LAMONT GEOLOGICAL OBSERVATORY
COLUMBIA UNIVERSITY
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NATURAL AND MAN-MADE ICE VIBRATIONS IN THE CENTRAL ARCTIC OCEAN IN THE FREQUENCY RANGE FROM 0.1 TO 100 CPS

by

David Prentiss, Edward Davis, and Henry Kutschale

Technical Report No. 4

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CONTENTS

ABSTRACT

During April and May, 1962, ice vibrations in the frequency range from 0.1 to 100 cps were measured aboard drifting ice island ARLIS II in the central Arctic Ocean. A vertical-component seismometer, which was anchored to the surface of the island, was employed as a detector. Typical displacement spectra show the following characteristics:

(1) a nearly constant decrease in amplitude with increasing frequency from 2.4×10^4 mμ at 0.1 cps to 1.0 mμ at 6 cps

(2) an amplitude minimum of 0.1 mμ between 6 and 10 cps

(3) an amplitude peak of 2 mμ between 30 and 70 cps.

The data show some correlation between local wind speed and the amplitudes of ice vibrations. Under the quietest conditions, which correspond to minimum local wind, the ice surface in the frequency band from 1 to 10 cps is quieter than a quiet land site. Under the most unfavorable conditions ambient vibrations in the frequency range from 30 to 80 cps approach those measured at noisy land sites. Local ice tremors, caused by ice fracture, enhance vibrations in the frequency range between 0.7 to 10 cps. These transient signals do not interfere significantly with SOFAR signal detection because of their short duration and characteristic dispersion. In a general way, the amplitude spectra of both local and SOFAR shots are in most cases strikingly similar to the ambient vibration spectra. In the 10-20 cps band the reverberation spectra rise smoothly from 6 to 10 db above the ambient level and are apparently independent of shot size, depth, and propagation path.

I. INTRODUCTION

All acoustic measurements used for this report were made over a 6-week period in April and May of 1962 on ice station ARLIS II in the central Arctic Ocean.

Figure 1 shows the locations where the measurements were made. The average ocean depth at these locations was approximately 2800 meters. At this time, the ice station was surrounded by 10/10 ice cover. The ice island has dimensions of 3.8 x 3.0 kilometers with an ice thickness varying between 6 to 25 meters.

In the following pages, instrumentation, methods of data analysis, and representative spectral curves are presented. The description of the various spectral features are also discussed and correlated with meteorological conditions. The results of ocean-bottom measurements obtained during the same period of time and location have been presented by Prentiss and Ewing (1963).

II. RECORDING TECHNIQUE

The basic instrumentation consisted of a 2-cycle vertical-component Hall-Sears geophone and associated electronics for the detection, amplification, and recording of the ice vibrations on magnetic tape. The detected signal was amplified and frequency modulated a 12 Kcps carrier. This signal was then transmitted to an electronic mixer. The mixer took a 13 Kcps signal from a beat frequency oscillator and mixed it with the 12 Kcps modulated signal thus producing a 1 Kcps difference frequency. This input frequency was then used to record the ice vibration signals on a magnetic tape recorder.

The Hall-Sears geophone was located at a distance of 200 meters from the recording instruments and 900 meters from the camp electrical generator. The ice thickness at the geophone location was 12 meters. This instrument was well coupled to the ice and was effectively protected against wind induced vibrations.

The entire recording system was initially calibrated using the Willmore Impedance Bridge technique (Willmore,1959). Two instruments were employed in these measurements. Instrument A used a low (20K) impedance Hall-Sears geophone with solid state circuits throughout which was modified in the field to protect it from radio frequency interference. Figure 2 shows Instrument A's initial and modified response curve. Figure 19 shows the system noise curve of Instrument A which set the lower limit of amplitudes that it could measure. Instrument B employed a hybrid circuit which used a 200K Hall-Sears geophone and vacuum tube preamplifier and transistors for the remaining stages.

Figure 2 includes its response curve and Figure 19 includes an estimate of its system noise based on the ideal thermal noise of a 200K impedance which experience has shown was the major limiting factor for this type of preamplifier.

All measurements were made with instrument A or A modified except one exceptionally quiet day when Instrument B's lower system noise was used to advantage.

About 15 hours of data was obtained during the 6-week period. The data is analyzed in 3 to 5 minute samples by the method described in the following section.

III. DATA REDUCTION

Before demodulation, the tape recorded carrier was amplified and clipped to produce a train of FM square waves, which were next passed through a Hewlett-Packard frequency meter. The frequency meter produced a series of negative pulses of constant width and amplitude whose repetition rate was proportional to the number of zero crossings per unit time of the square wave input. By passing this train of pulses through a Khronhite band-pass filter, the original ice vibrations are recovered. From samples of tape, 3 to 5 minutes in duration, a measurement is made of the envelope of the peak-to-peak amplitudes present for 95% of the time in the sample analyzed. This is done directly on a visual Sanborn chart recording. By varying the band-pass frequency for the same section of tape, successive displacement amplitudes centered in an octave band about each filter setting are obtained. Since the filter has an insertion loss of 6 db, which is a factor of 2, one can directly convert the peak-to-peak envelope to zero-to-peak displacement spectra by applying the appropriate magnification curves for the combined recording-analysis instrumentation.

The above procedure for data reduction was also used to make a spectral analysis of the transient signals recorded. In this case, the maximum rather than average displacement is used in determining the spectra.

IV. RESULTS

A. The Ambient Noise Spectrum. It is felt that the samples analyzed accurately represent the variations in the ice vibrations over the period data were recorded. Figures 3 to 17 show these curves. These spectral curves have several characteristic features. The analysis shows a minimum point in the region of 6 to 10 cps, a maximum point in the region of 30 to 70 cps, and a general increase of displacement amplitude at frequencies below 6 cps. A small peak or knee is observed at about 1 cps.

The ambient noise in all cases has a spectral minimum varying between 6 to 10 cps. This minimum fluctuates in displacement from approximately .02 mμ to .4 mμ. For those analyses extending to 100 cps, a maximum in the spectra at 30 to 70 cps was observed. This maximum fluctuates in displacement from approximately .3 mμ to 2.5 mμ and varies with wind speed. The center frequency and width of this maximum also varies, but a sufficient number of measurements to clearly establish a wind dependence have not yet been made. At frequencies below 6 to 10 cps a general increase in the displacement spectra occurs with decreasing frequency. This increase in displacement with decreasing frequency is typical of the Arctic Ocean spectra for wave amplitudes (Hunkins, 1962). Figure 18 compares the maximum and minimum ambient curves measured in the present experiment with the wave amplitude spectra on the Arctic Ocean presented by Hunkins.

Camp generator noise may have an effect on the spectral curves at frequencies above 20 cps. The variance in spectral character, displacement and position of the high frequency spectral maximum would seem to refute this since a constant source of noise would be localized at one particular frequency and displacement.

The ice surface and ocean bottom have similar spectral characteristics in the frequency range from 1 cps to 10 cps, (Prentiss and Ewing, 1963). This similarity of the spectra led Prentiss and Ewing to suggest that the ice layer, water layer, and bottom sediments form a single acoustic system for the propagation of noise from 1 to 10 cps.

A comparison of the ambient noise curves (Figures 19 and 20) has been made with the Brune-Oliver (1959) curves for land noise. The Brune-Oliver curves have a spectral peak at a period of 8 seconds and decrease with increasing frequency. The maximum ambient measured in the Arctic Ocean is about the level of the average land noise curve and the minimum ambient is about a factor of 2 below the minimum curve for land noise. This shows that the Arctic Ocean surface at times is quieter than the average quiet land site. The curves for the ambient noise increase with decreasing frequency and lack the spectral peak of the Brune-Oliver curve. The absence of this spectral peak in the Arctic Ocean wave amplitude spectrum was first observed by Hunkins (1962).

A comparison of the spectral displacement amplitude of the ambient noise at the various pass-band center frequencies indicates that some relation between the spectral character and

wind speed may exist. Figures 21 to 24 illustrate this possible dependency on wind speed. The figures show that increasing wind velocity is accompanied by increasing spectral amplitudes. However, the ice noise increase lags the wind increase by 12 - 24 hours. A similar result was observed by Greene and Buck (1964). Frequencies below 20 cps seem to be all equally affected by the wind.

B. Transient Signals. The transient signals analyzed for their spectral characteristics were of two types -- natural ice tremors and SOFAR shots fired at various depths and of different charge sizes. Figure 25 is a sound spectrogram of a SOFAR shot showing pre-shot ambient, SOFAR signal, and reverberation.

Figures 26 and 27 illustrate the spectral characteristics of two types of ice tremors that can be considered representative of the April to May time period. The solid curve represents a long, ragged flexural wave train and the dashed line represents a simple flexural wave exhibiting characteristic dispersion clearly. In each set of curves shown, the ragged flexural wave followed the clean flexural wave (See Figure 20). Both the clean and ragged flexural waves exhibit similar spectral characteristics at frequencies below 10 cps. An increasing amplitude displacement with a predominant peak at approximately 1 cps is observed in the flexural waves. This peak is 2 orders of magnitude greater than a similar feature in the ambient noise spectra. Its character suggests that distant ice tremors also contribute to the wind generated

ambient around 1 cps. Above 10 cps the spectral character of the ice tremors analyzed varies. This change in the high frequency spectrum is probably due to the path of propagation and the nature of the stresses initiating the tremor.

The second type of transient signals analyzed were SOFAR shots fired from two locations in the Arctic Ocean. The shots were fired from ice station T-3, 800 kilometers southeast of ARLIS II, whose position varied from $74^{\circ}32'$N, $166^{\circ}06'$W to $74^{\circ}49'$N, $167^{\circ}03'$W, and from the polar pack ice 1300 kilometers east of ARLIS II at approximately 80°N and 120°W. The shot depth and size was varied to study the effects of various modes of propagation (Kutschale, 1961).

The spectral curves for the SOFAR shots (Figures 29 to 36) have a spectrum strikingly similar to the ambient noise spectrum. The shot spectrum has a minimum between 4 and 10 cps. At lower frequencies the curves increase again with a knee present on several of the spectra near 1 cps. Several shot spectra exhibit a high frequency maximum which is also observed in the ambient noise spectra. The shot spectra maximum is present in the region of 20 to 50 cps. The presence of these frequencies may be due to bubble pulses at the source. At lower frequencies the ambient and shot spectral curves are of the same order of magnitude. Variability in the shot spectrum is due to the path of propagation, depth of charge, the strength of the charge and the type of explosive.

C. <u>Reverberations After Shots</u>. The reverberations following both SOFAR and local shots were examined for their spectral characteristics. The ice vibrations 1 second before the shot and 3 seconds after the shot were measured (See Figure 25). Figures 37 to 40 illustrate these spectra.

A comparison of the spectra before and after a SOFAR shot indicates that the spectral components are of a similar nature. The ambient curve is enhanced by a factor of 2. The reverberation gradually decayed within several minutes to the original ambient level.

A local shot fired approximately 1000 meters from the recording instrumentation was analyzed as well as the pre-shot ambient and successive samples of reverberation. Figure 41 shows this spectral analysis. Because of the high level of the reverberations, the rate of decay to ambient levels can clearly be seen. The spectrum of the shot was very similar to the pre-shot ambient and about 2 orders of magnitude greater.

As the decay to the ambient is approached, it should be noted that the character of both SOFAR and local shots maintains a similar shape, except in the band 10 to 20 cps where the reverberation amplitudes are from 6 to 10 db higher than the ambient spectrum. Figure 42 is a summary plot of the ratio of the reverberation amplitudes to the ambient amplitudes of the four SOFAR shots and local shot analyzed. This 10 to 20 cps feature is immediately apparent on Figure 42 and persists in spite of variations in shot size, depth, and propagation path.

V. SUMMARY

1. The amplitude of the ambient noise, its spectral character, both in displacement and shape is inferred to be dependent in some way on the local wind.
2. In some cases, the minimum in the noise spectrum between 6 and 10 cps is favorable to SOFAR signal detection because of the enhanced signal to noise ratio in this frequency region.
3. There is a maximum in the noise spectrum between 40 and 80 cps in those measurements that were extended to 100 cps.
4. Ice tremors increase the ambient level in band 1 to 10 cps.
5. The similarity between spectral curves of surface measurements and ocean bottom measurements suggests local wind coupling of energy into the ocean.
6. SOFAR and local shots have in many cases a strikingly similar spectral character to the noise ambient.
7. The reverberations following nearby and distant explosions are significantly higher (6 to 10 db) than the ambient in the band 10 to 20 cps.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. K. Hunkins and the Lamont Arctic section for many hours of discussion of the data and for much fruitful criticism of its interpretation.

Special thanks are extended to Dr. Max Brewer, director of the Arctic Research Laboratory; to the pilots and to the station personnel of the late ARLIS II and to J. Pew of the University of Wisconsin for unstinting support of the Arctic work.

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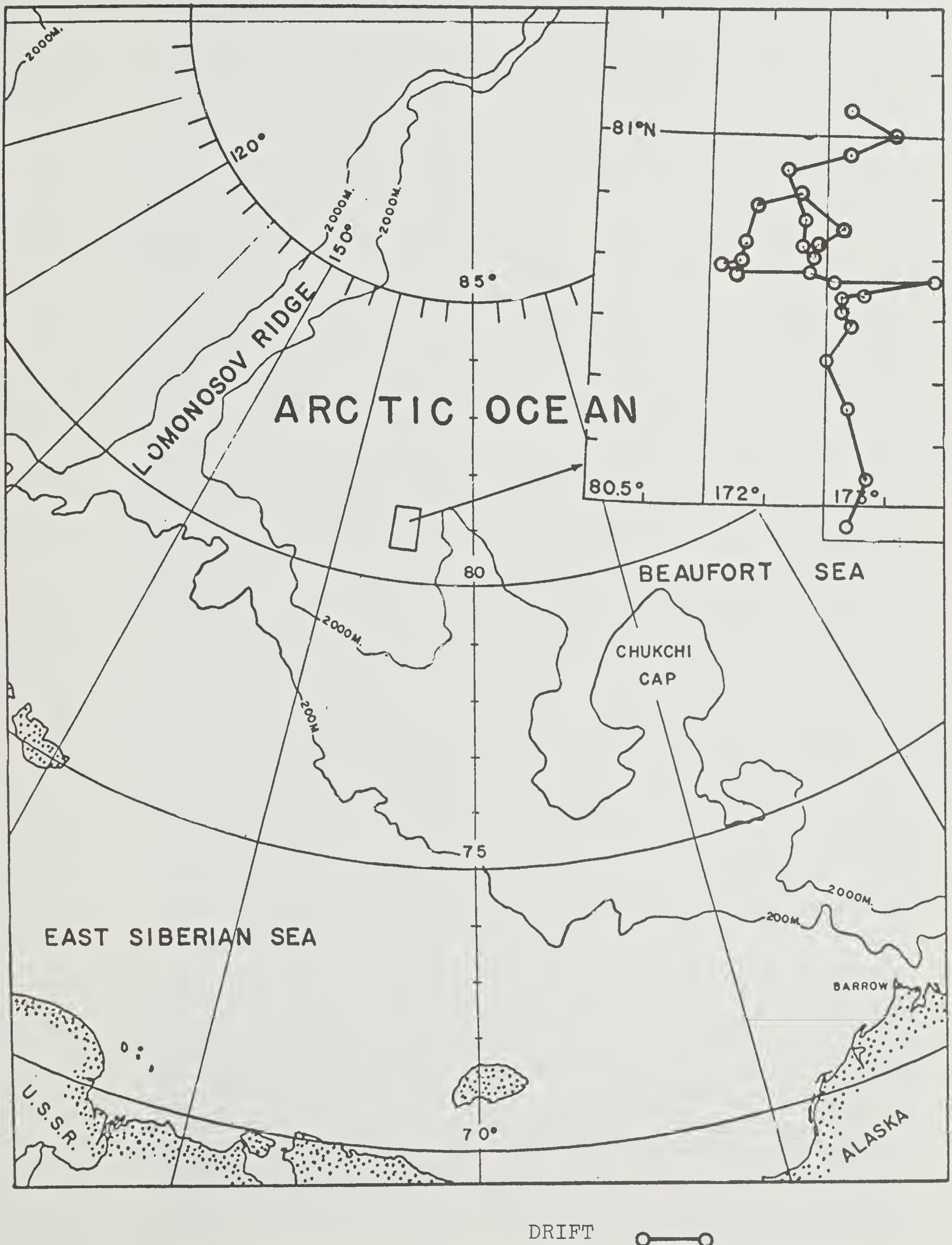
Greene, C. R., and B. M. Buck, Directional, spectral, and statistical properties of the under-ice noise in the Arctic, G. M. Defense Res. Lab. Tech. Rep., 64-22, March 1964, 23 pp.

Hunkins, K., Waves on the Arctic Ocean, J. Geophys. Res., 67, 2477-2489, 1962.

Prentiss, D. D., and J. I. Ewing, The seismic motion of the deep ocean floor, Bull. Seism. Soc. Am., 53, 765-781, 1963.

Willmore, P. L., The application of the Maxwell Impedance Bridge to the calibration of electromagnetic seismographs, Bull. Seism. Soc. Am., 49, 99-114, 1959.

Figure 1.   LOCATER MAP



DRIFT TRACK

Figure 2. RESPONSE CURVES

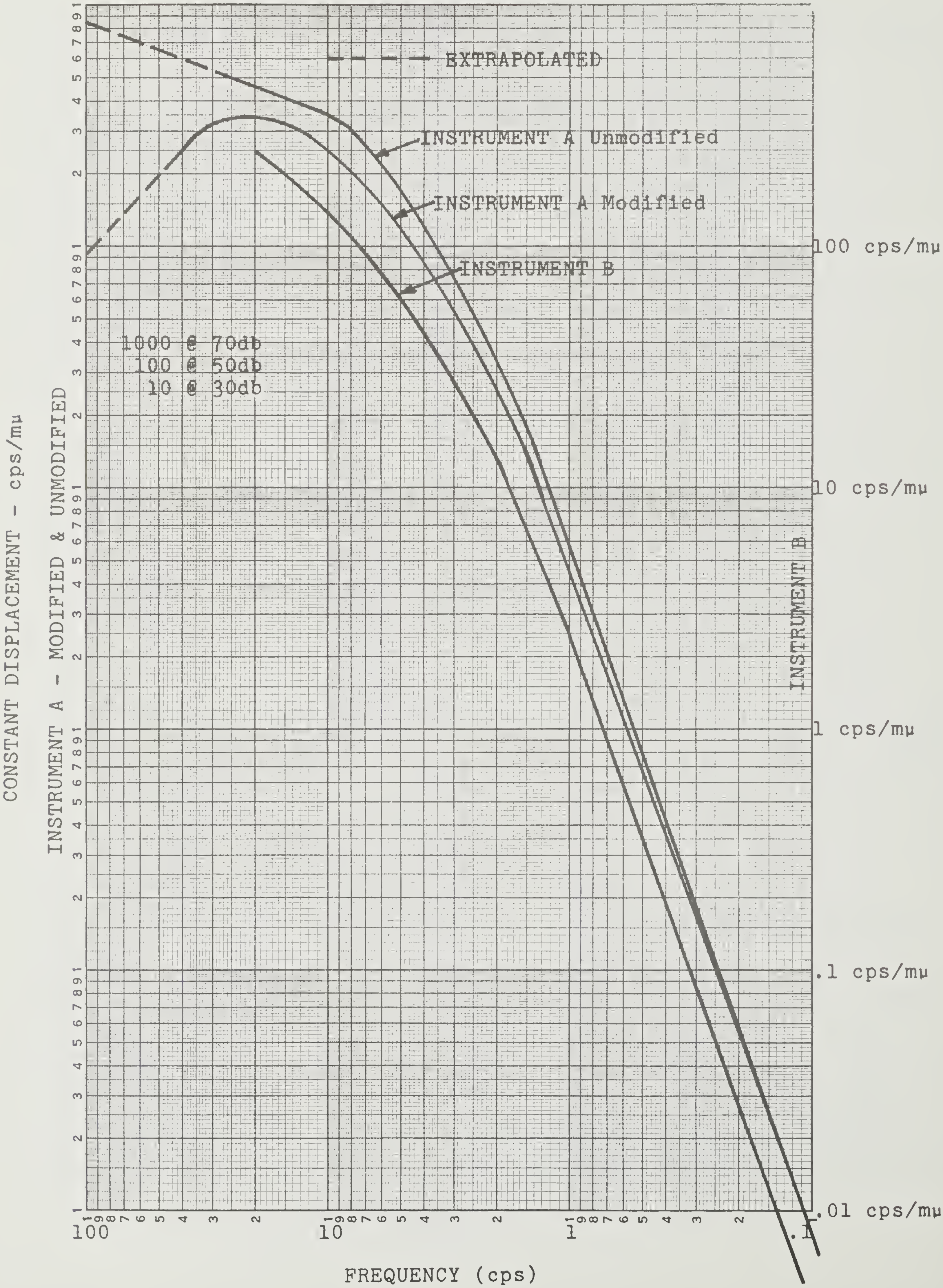


Figure 3. ICE AMPLITUDES 18 April 62

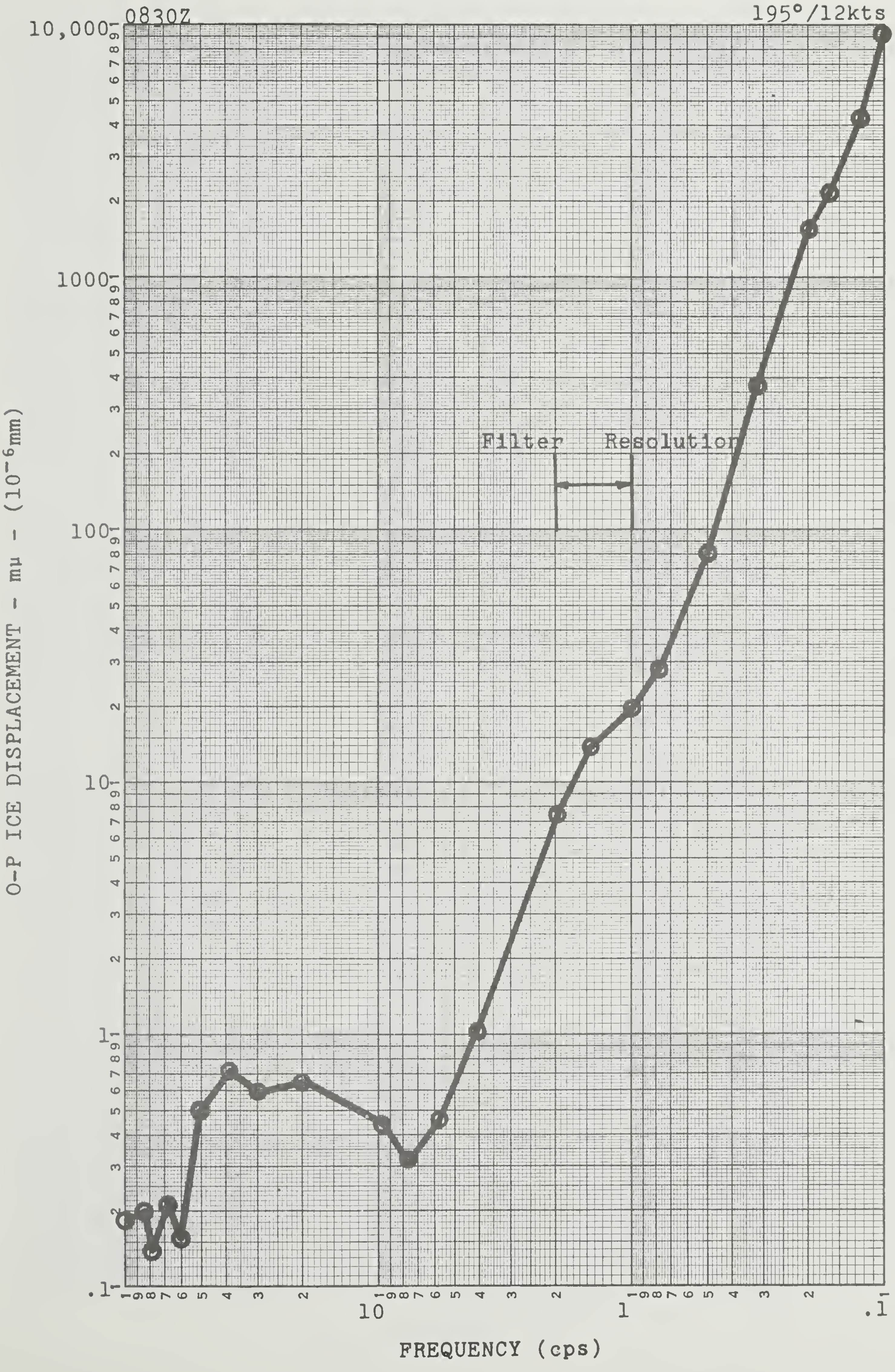


Figure 4.   ICE AMPLITUDES 20 April 62

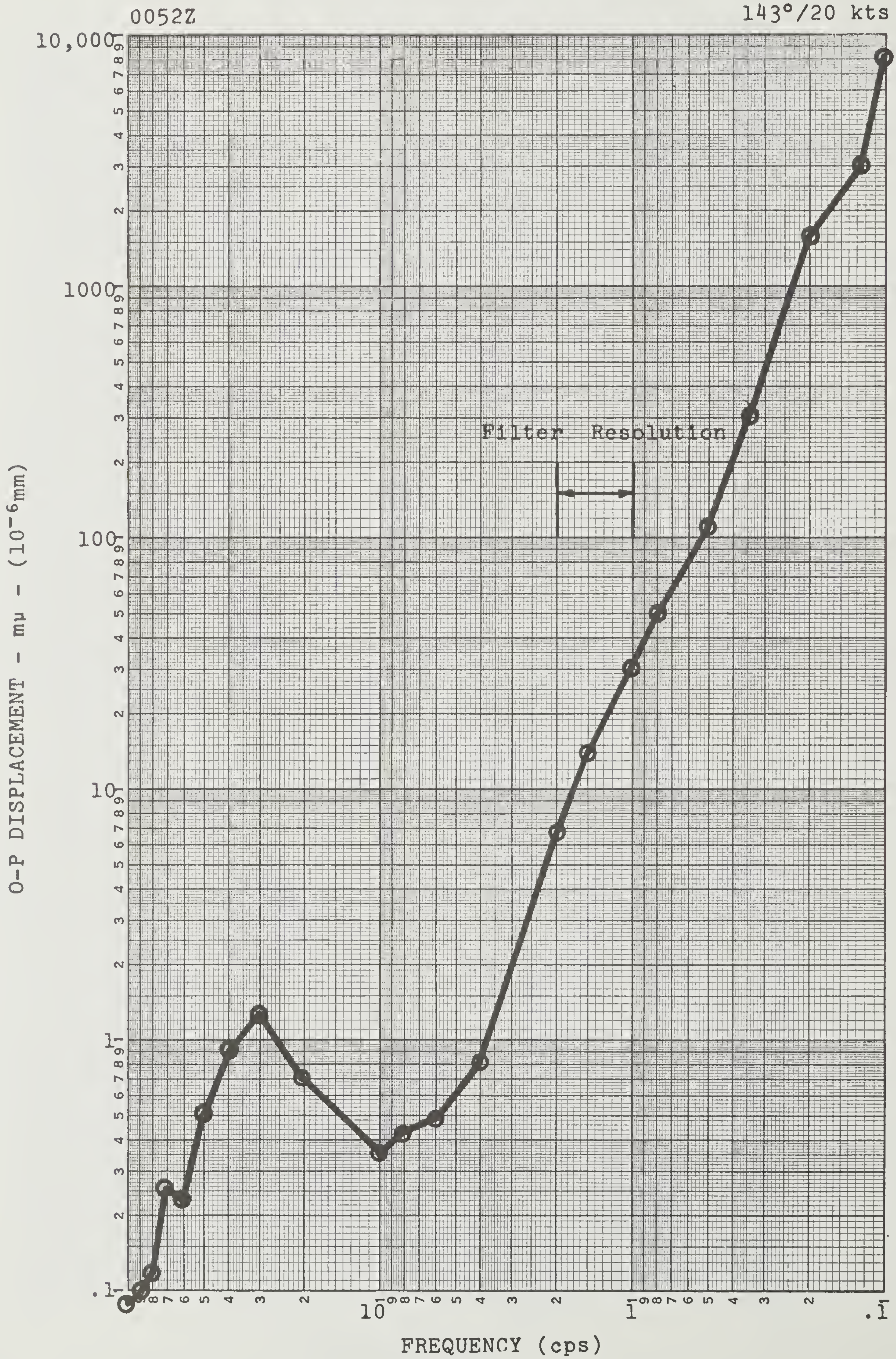


Figure 5. ICE AMPLITUDES 20 April 62

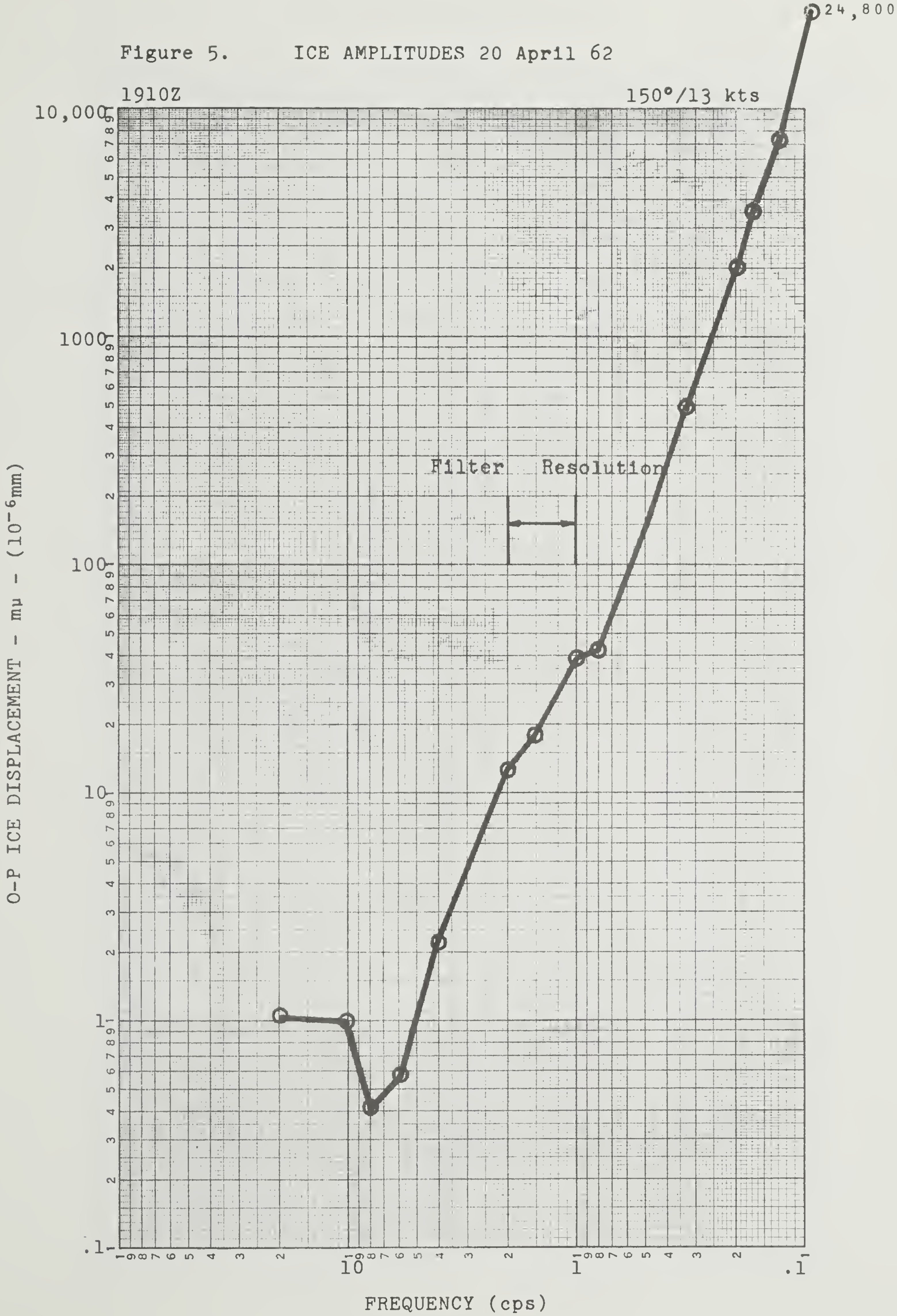


Figure 6. ICE AMPLITUDES 25 April 62

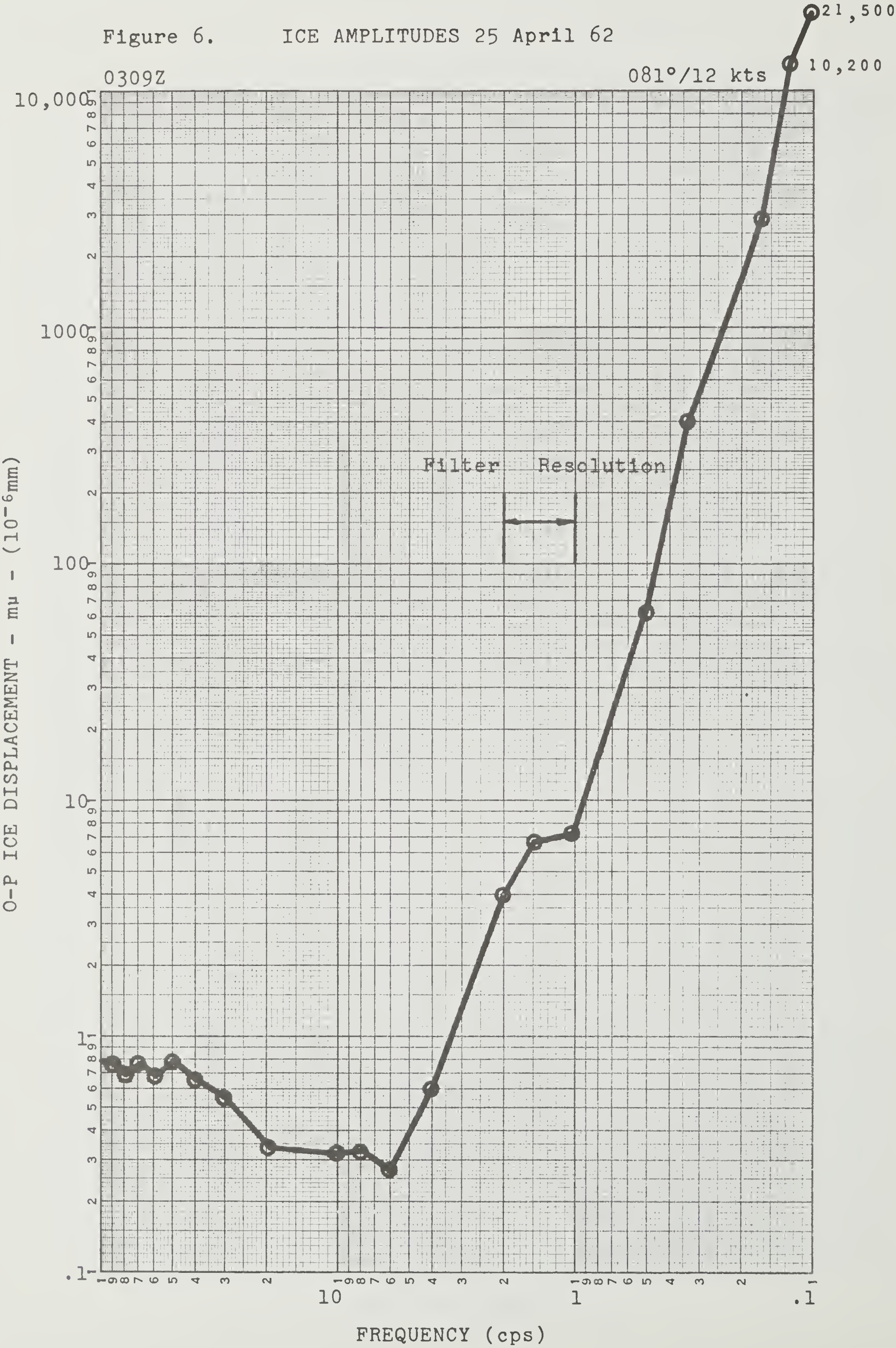


Figure 7. ICE AMPLITUDES 25 April 62

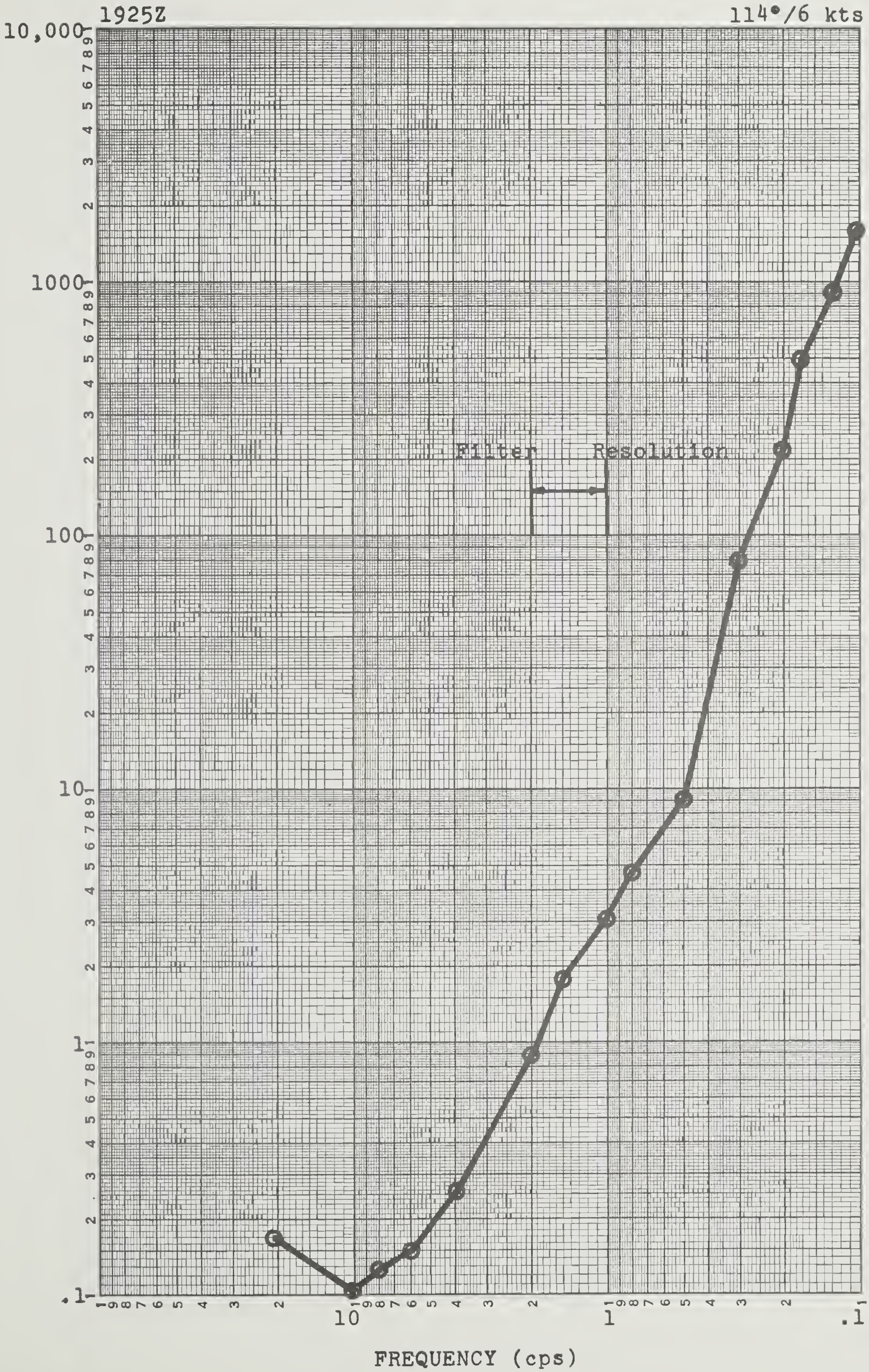


Figure 8. ICE AMPLITUDES - 26 April 62

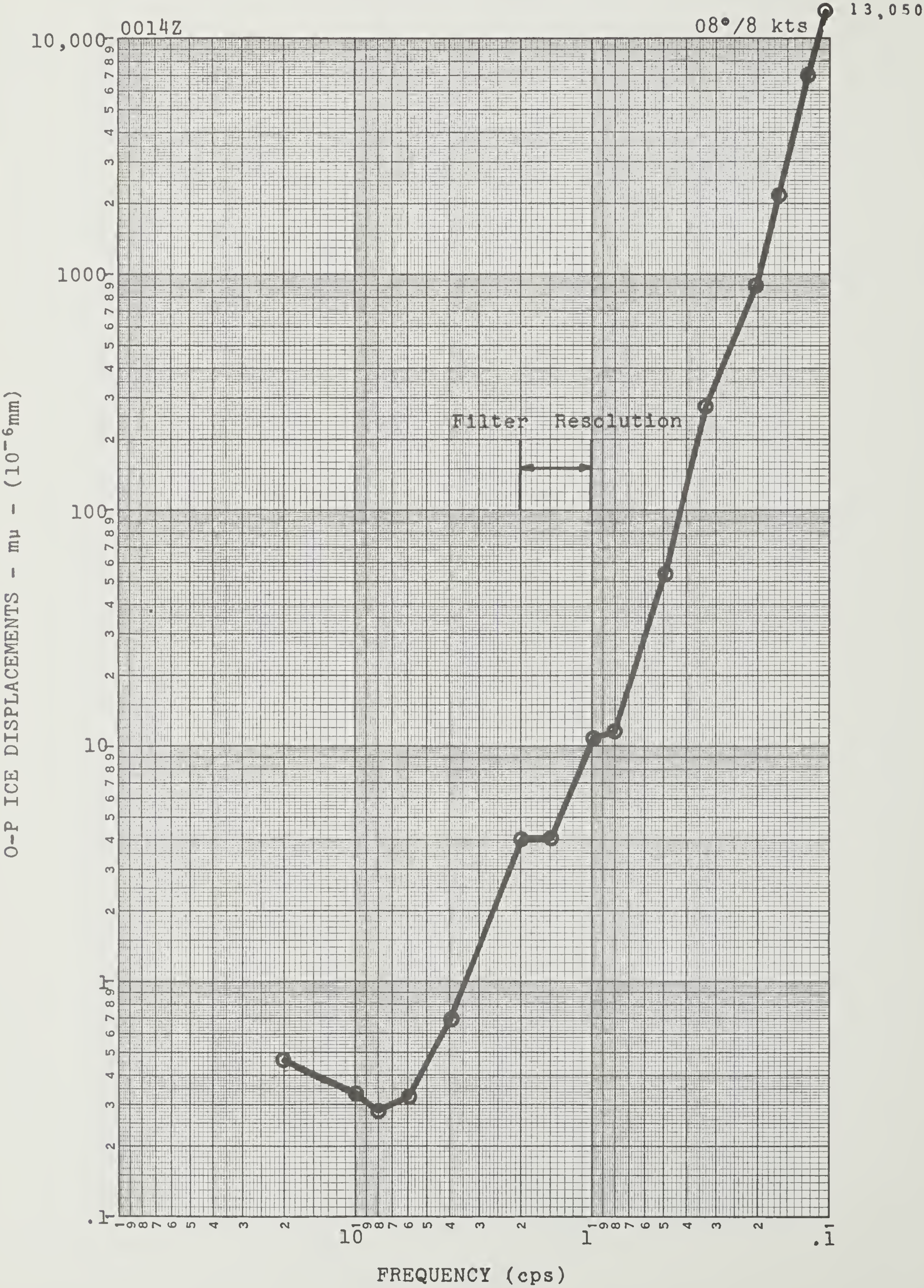


Figure 9.   ICE AMPLITUDES 26 April 62

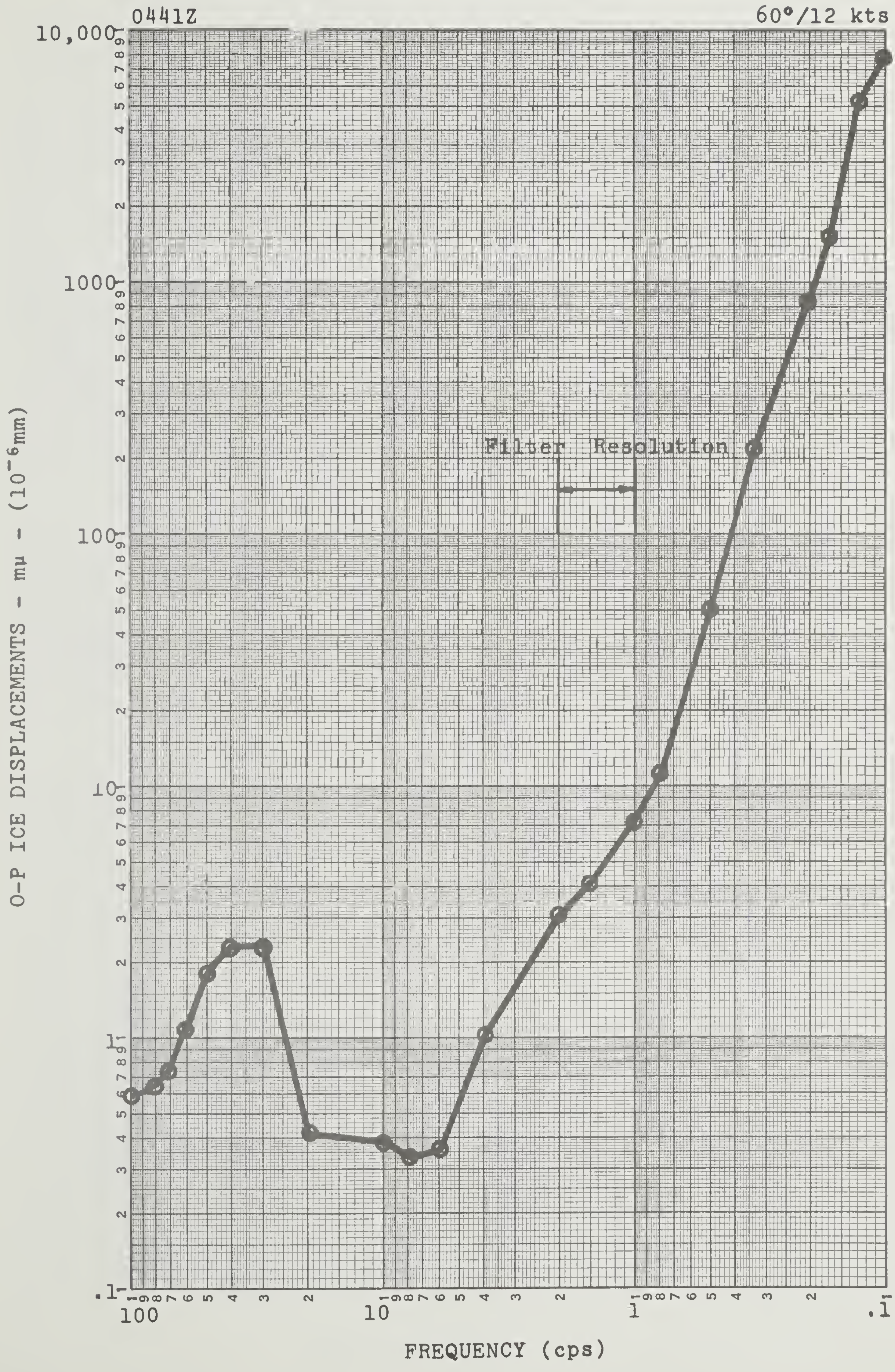


Figure 10.   ICE AMPLITUDES 27 April 62

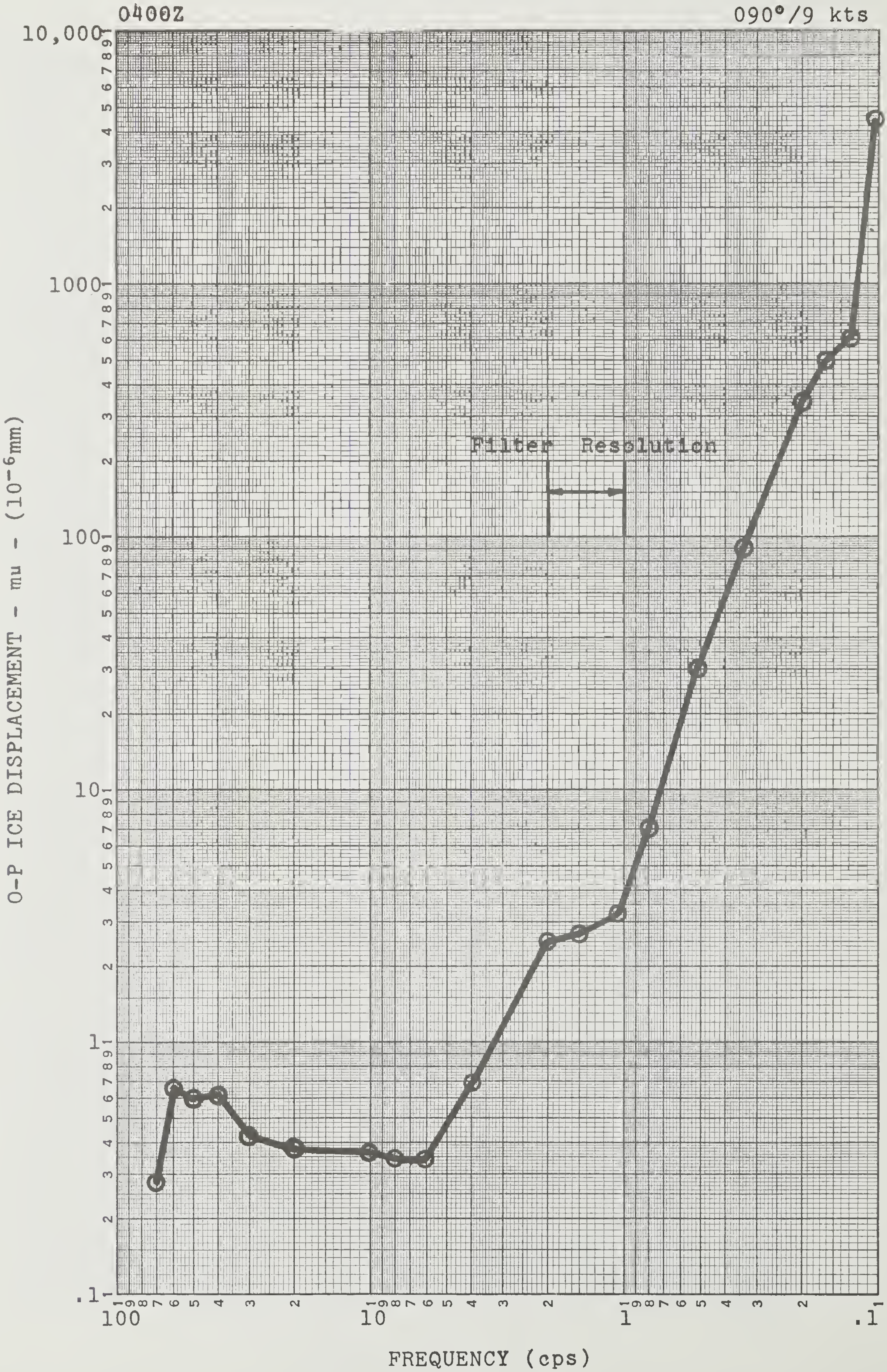


Figure 11. ICE AMPLITUDES 27 April 62

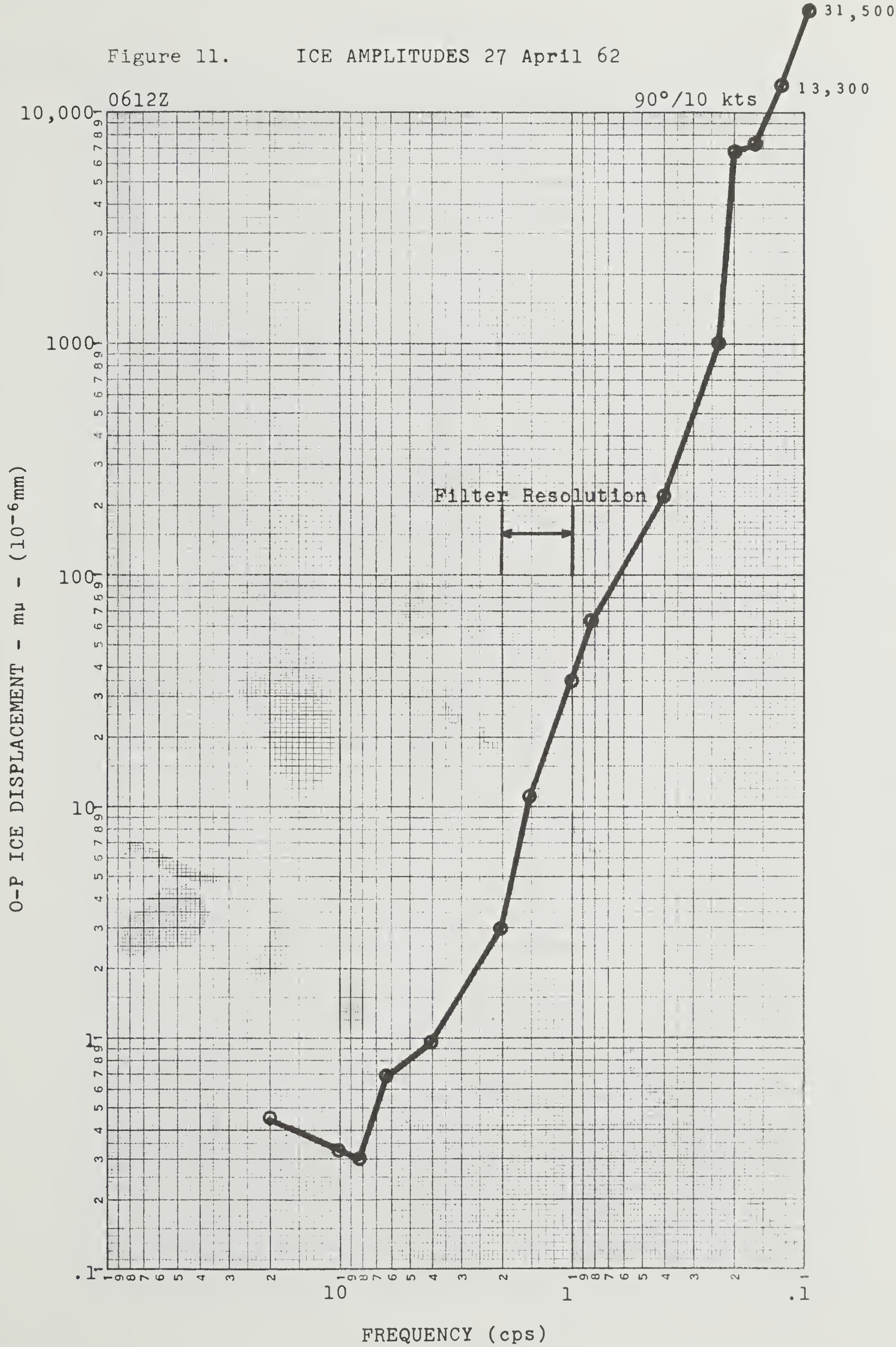


Figure 12. ICE AMPLITUDES 27 April 62

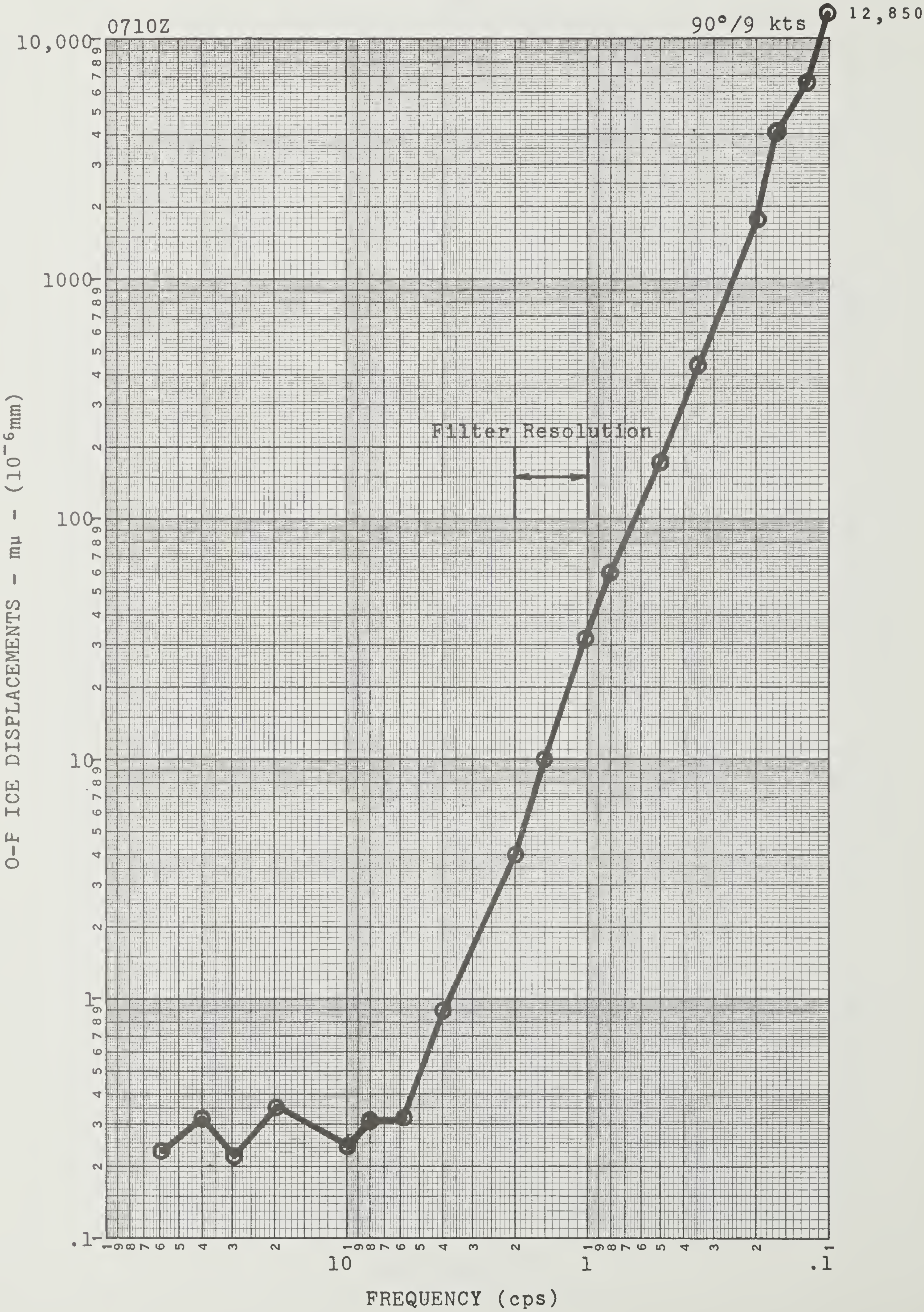


FIGURE 13. ICE AMPLITUDES 28 April 62

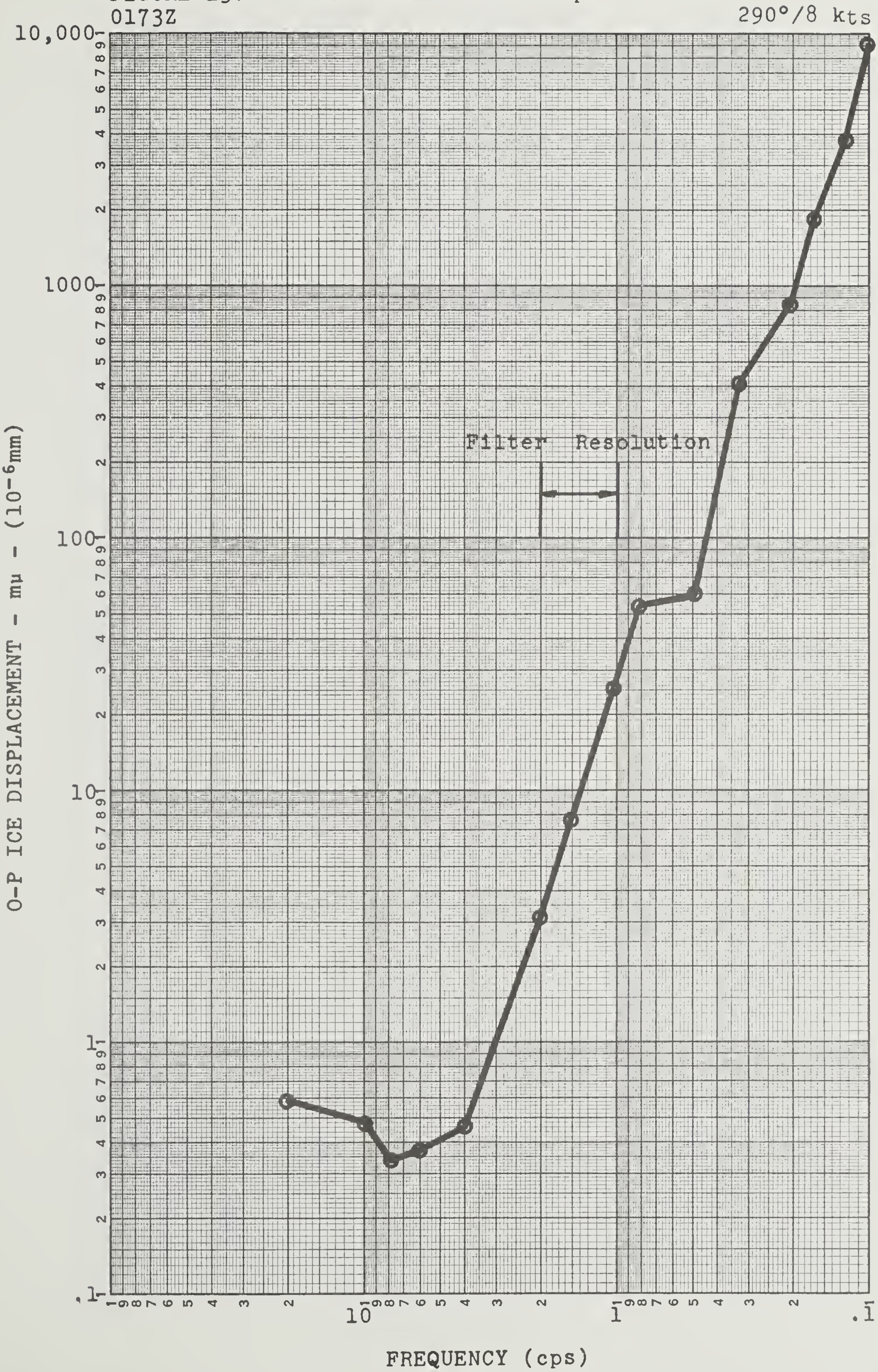


Figure 14. ICE AMPLITUDES 9 May 62

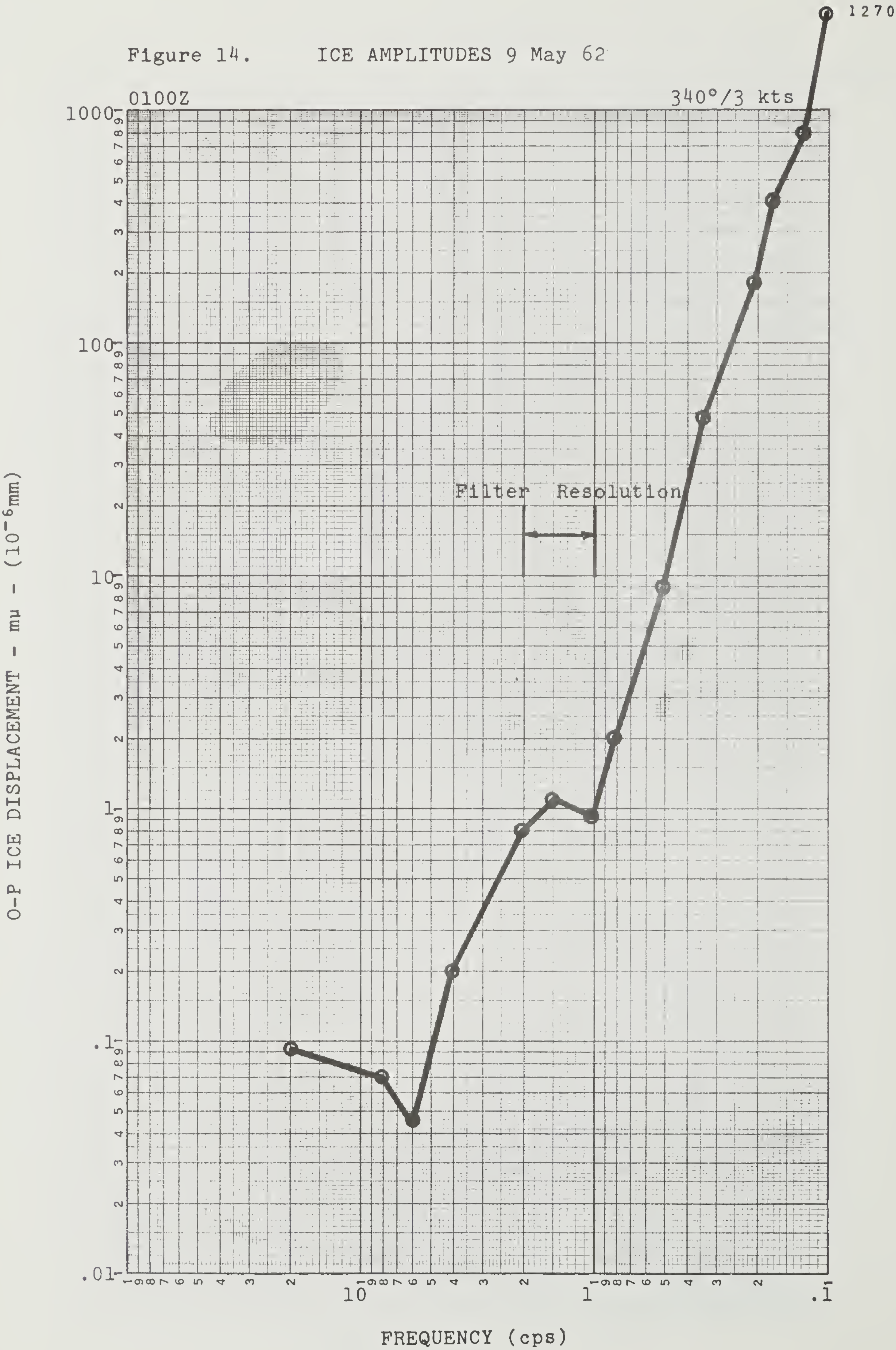


Figure 15. ICE AMPLITUDES 10 May 62

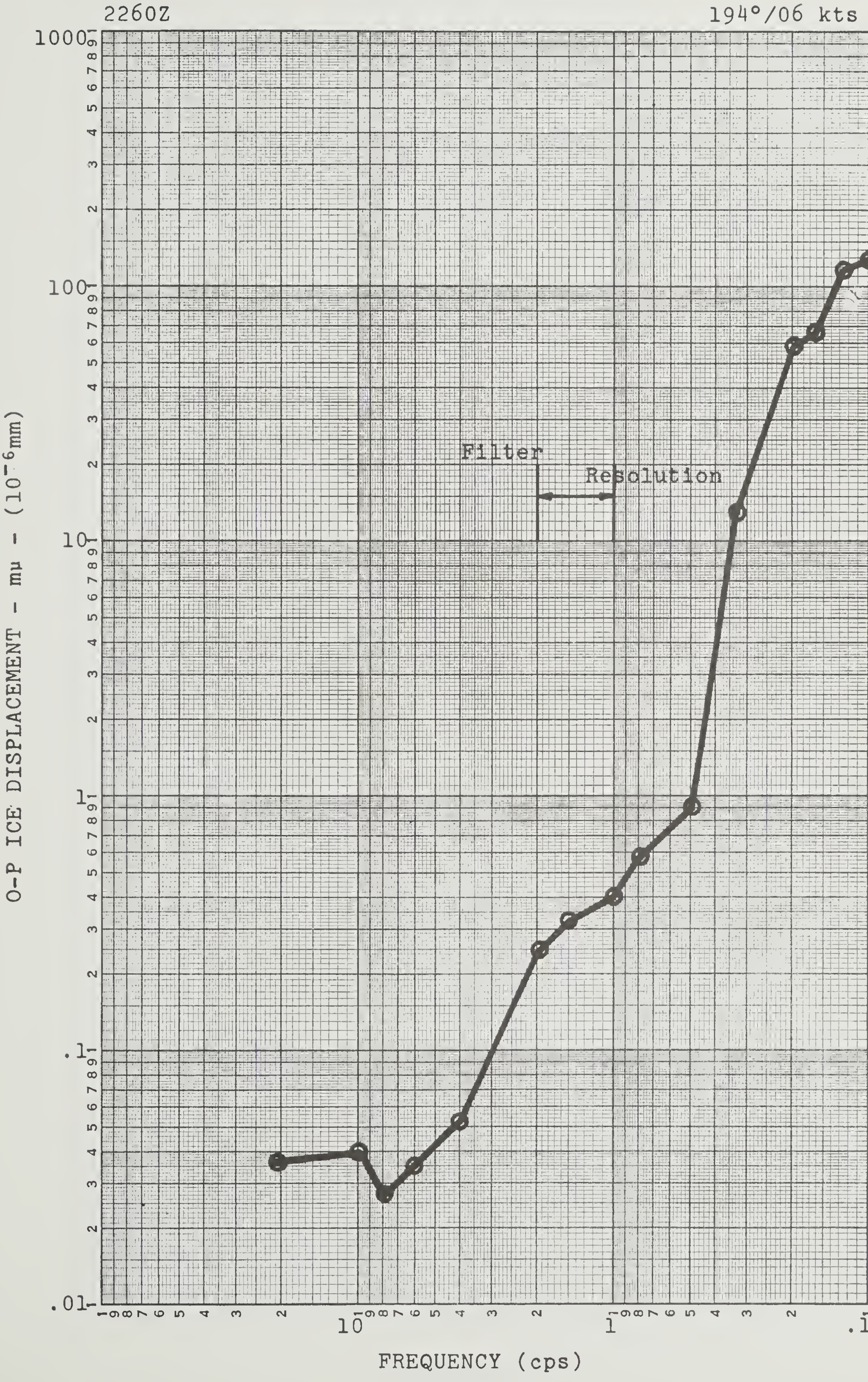


Figure 16. ICE AMPLITUDES 11 May 62

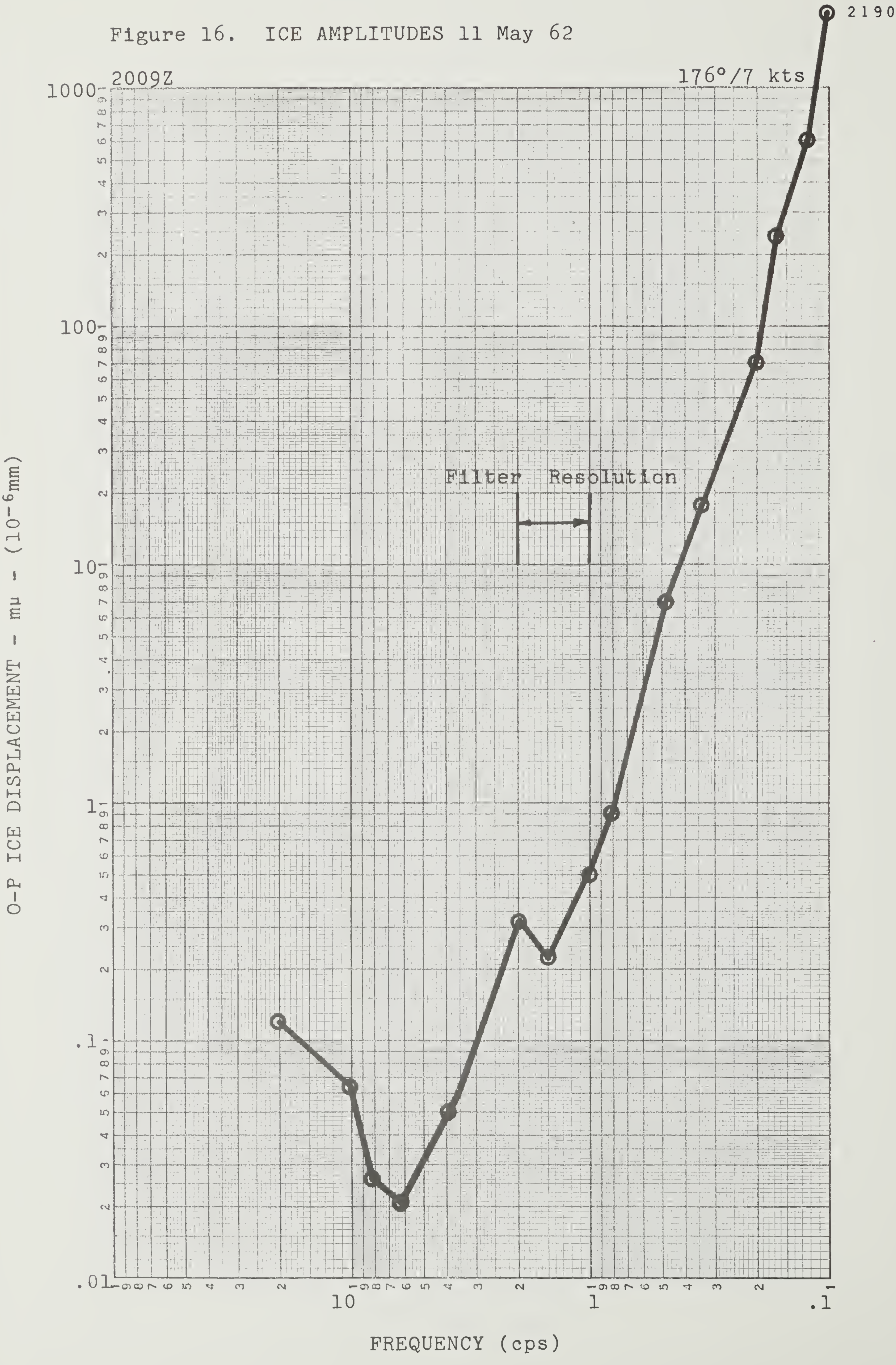


Figure 17. ICE AMPLITUDES 14 May 62

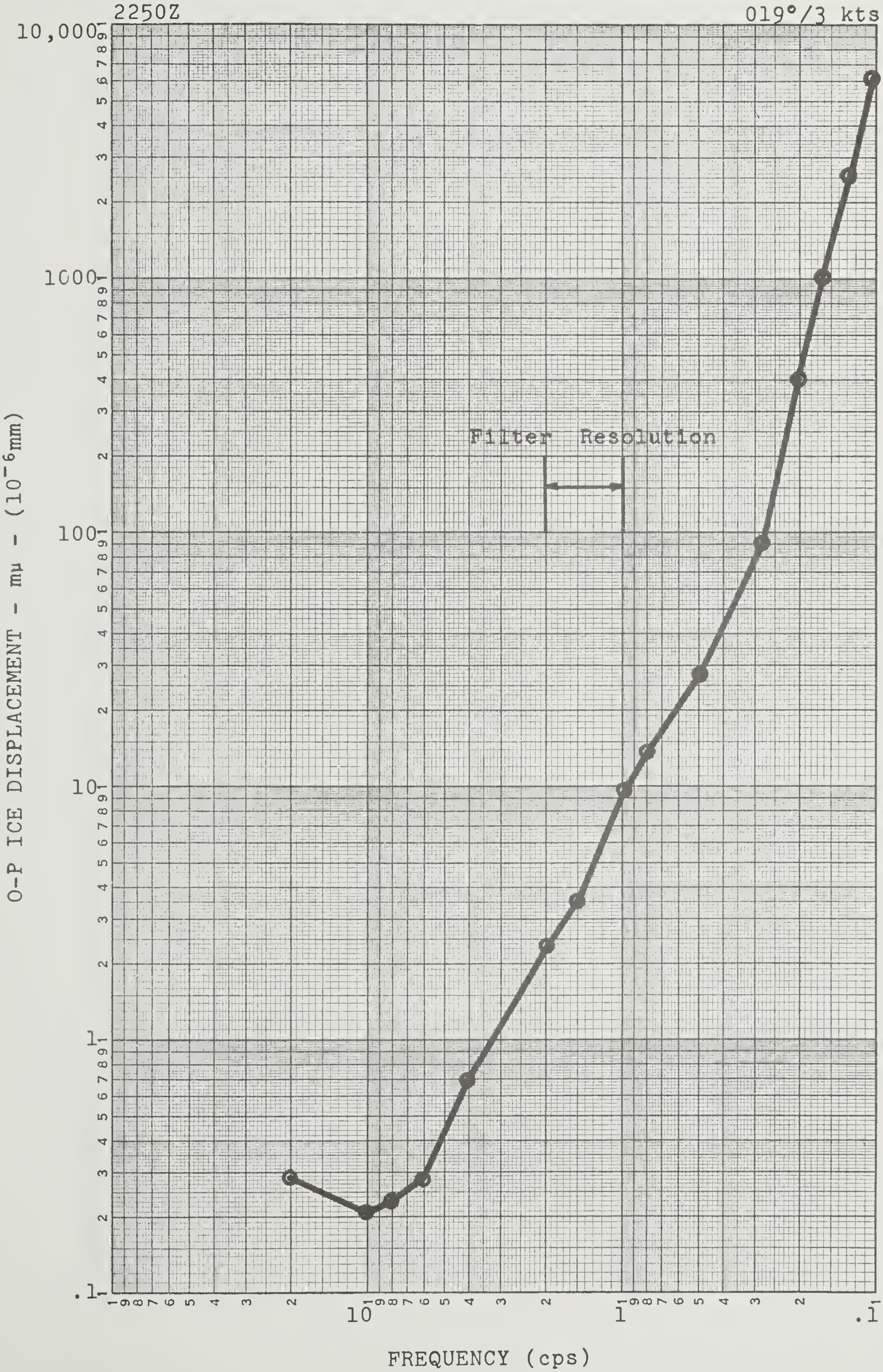
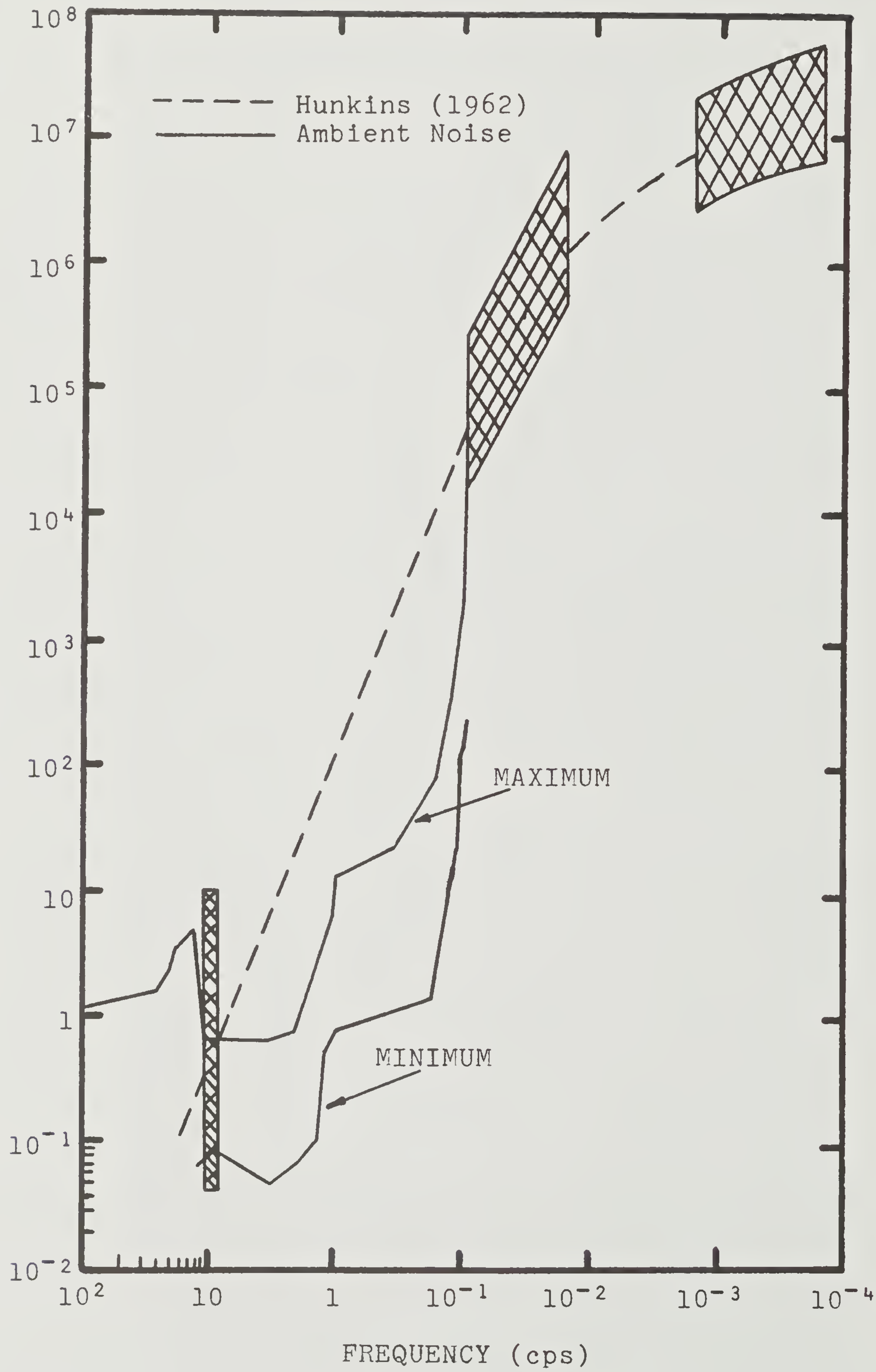


Figure 18.



Hunkins (1962)
Ambient Noise
MAXIMUM
MINIMUM
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
FREQUENCY (cps)

Figure 19.

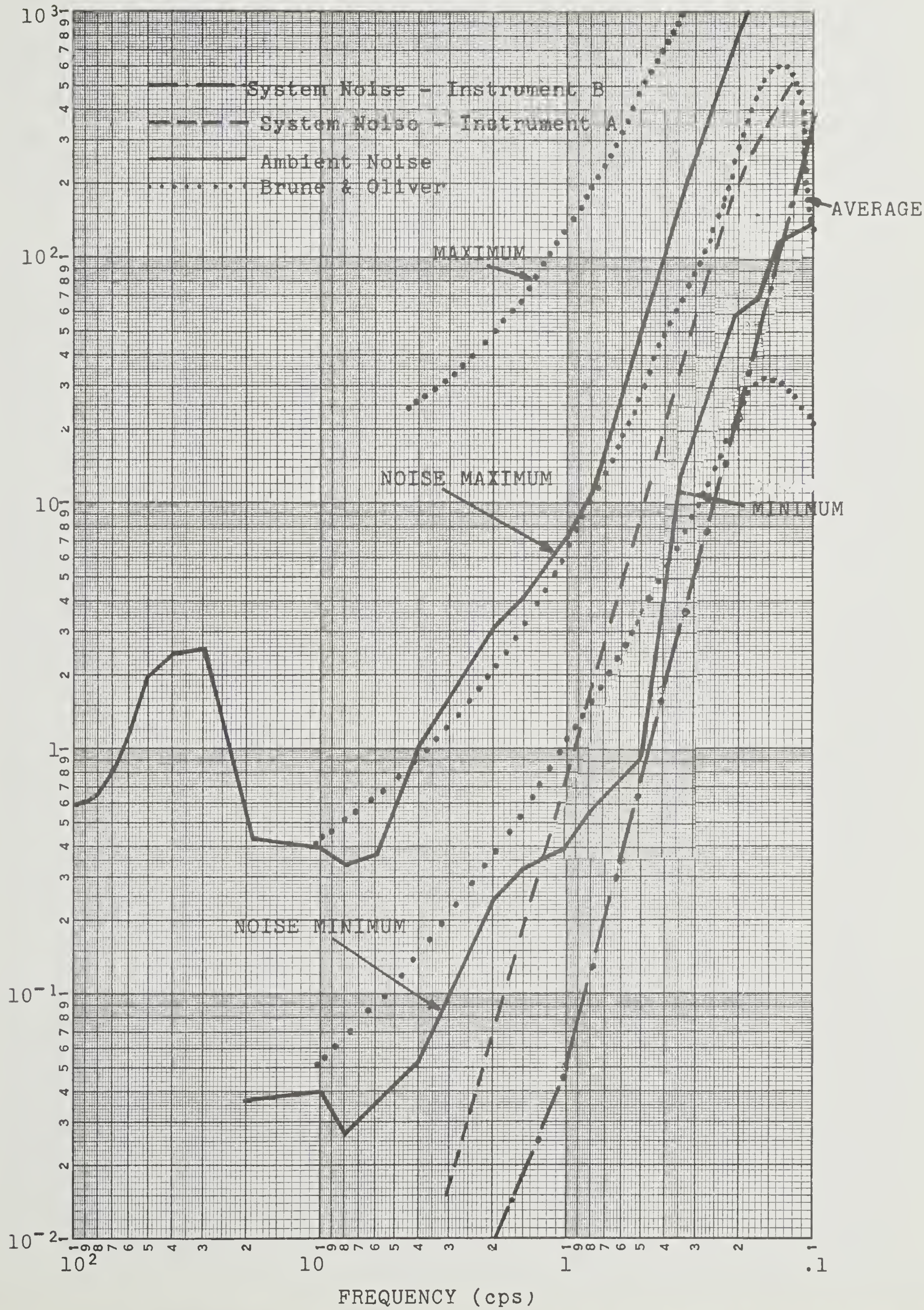
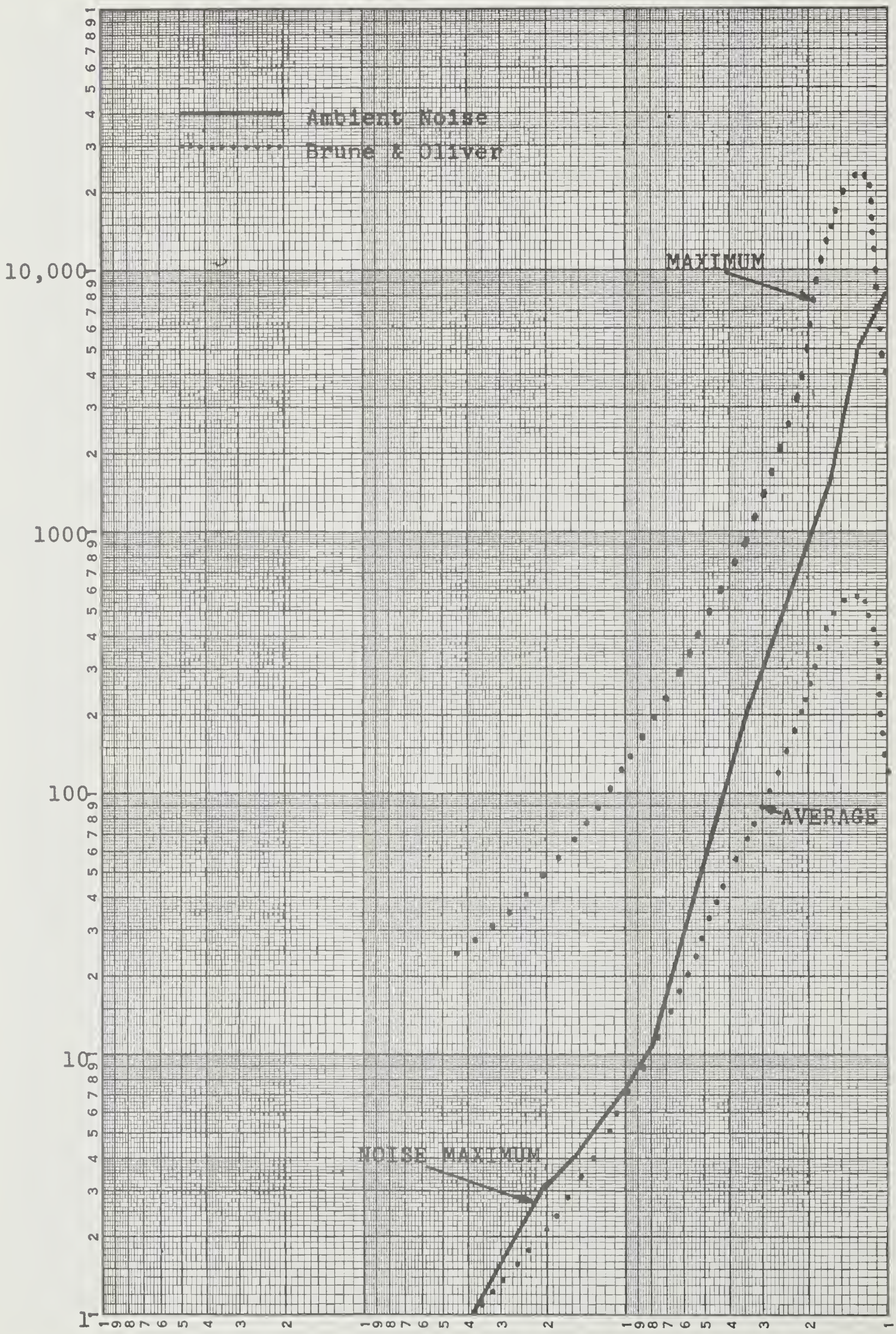

System Noise - Instrument B
System Noise - Instrument A
Ambient Noise
Brune & Oliver
MAXIMUM
AVERAGE
NOISE MAXIMUM
MINIMUM
NOISE MINIMUM
O-P DISPLACEMENT - mμ
FREQUENCY (cps)
10^3
10^2
10
1
10^{-1}
10^{-2}
10^2
10
1
.1

Figure 20.



Ambient Noise
Brune & Oliver
MAXIMUM
AVERAGE
NOISE MAXIMUM
10,000
1000
100
10
1

Figure 21. April 1962

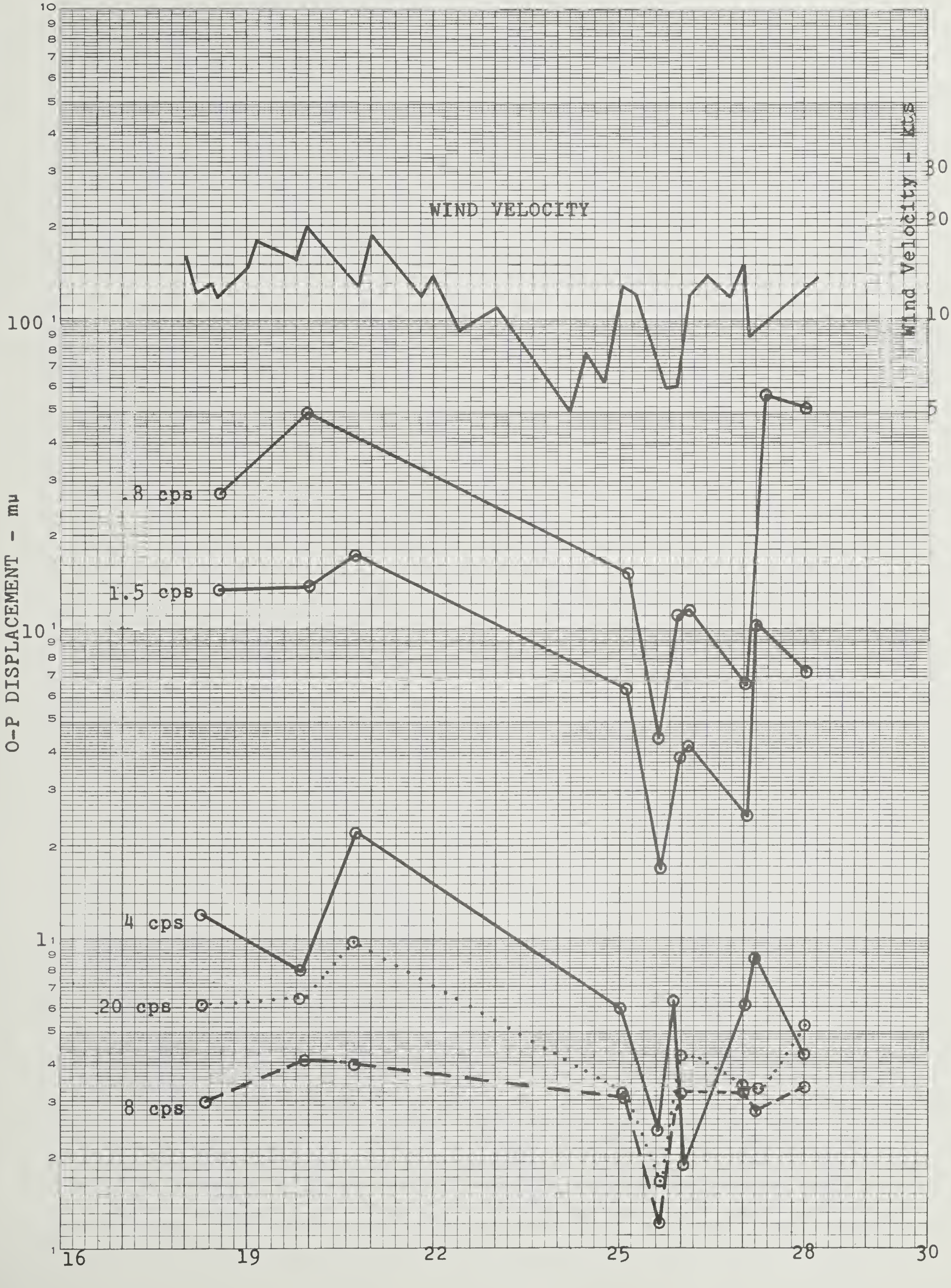


Figure 22. April 1962

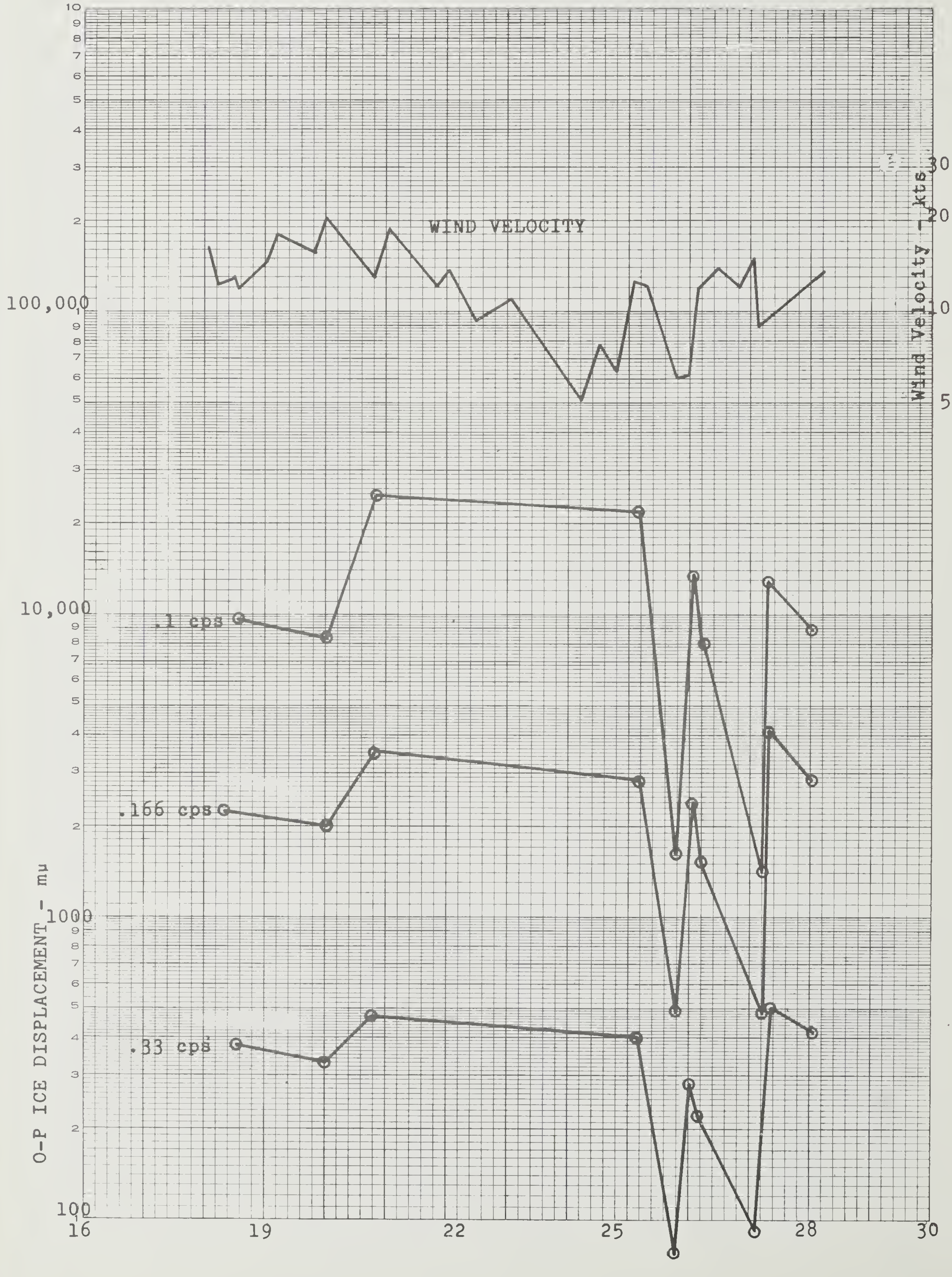


Figure 23.   May 1962

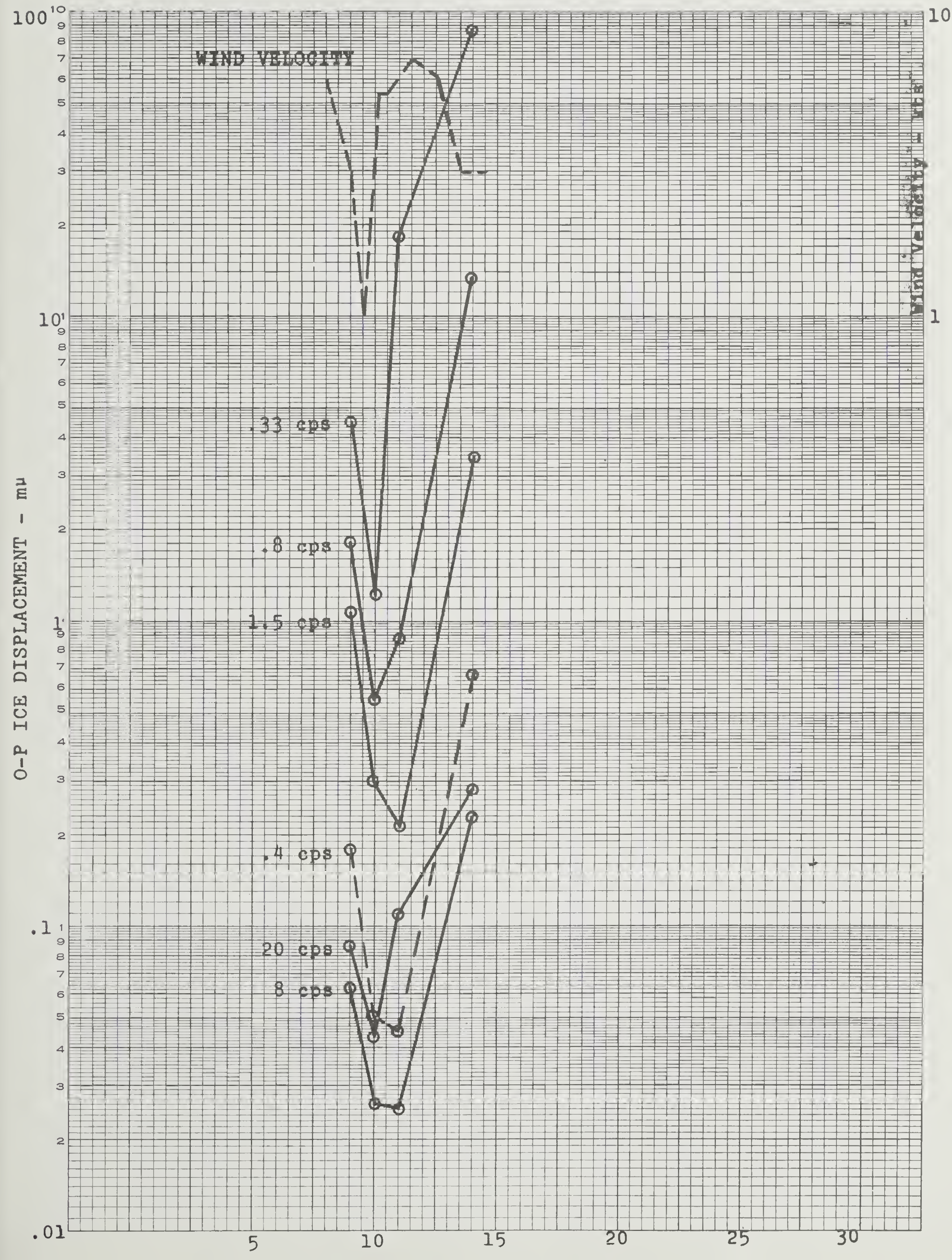


Figure 24.   May 1962

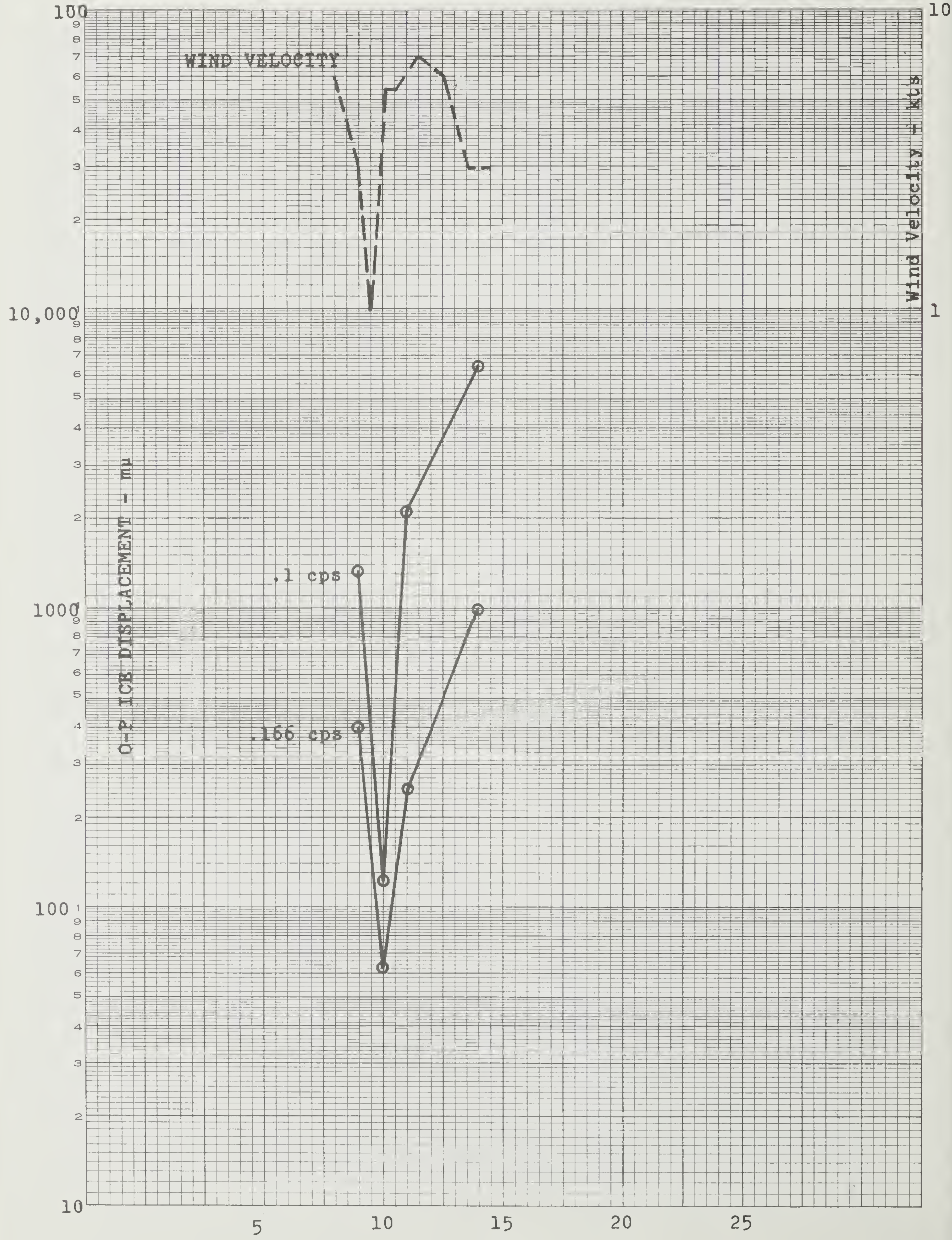


Figure 25.

SOUND SPECTROGRAM
SEISMOMETER ON ICE
5 1/2 lbs. at 600 feet, T-3 firing
High Cutoff 100 cps

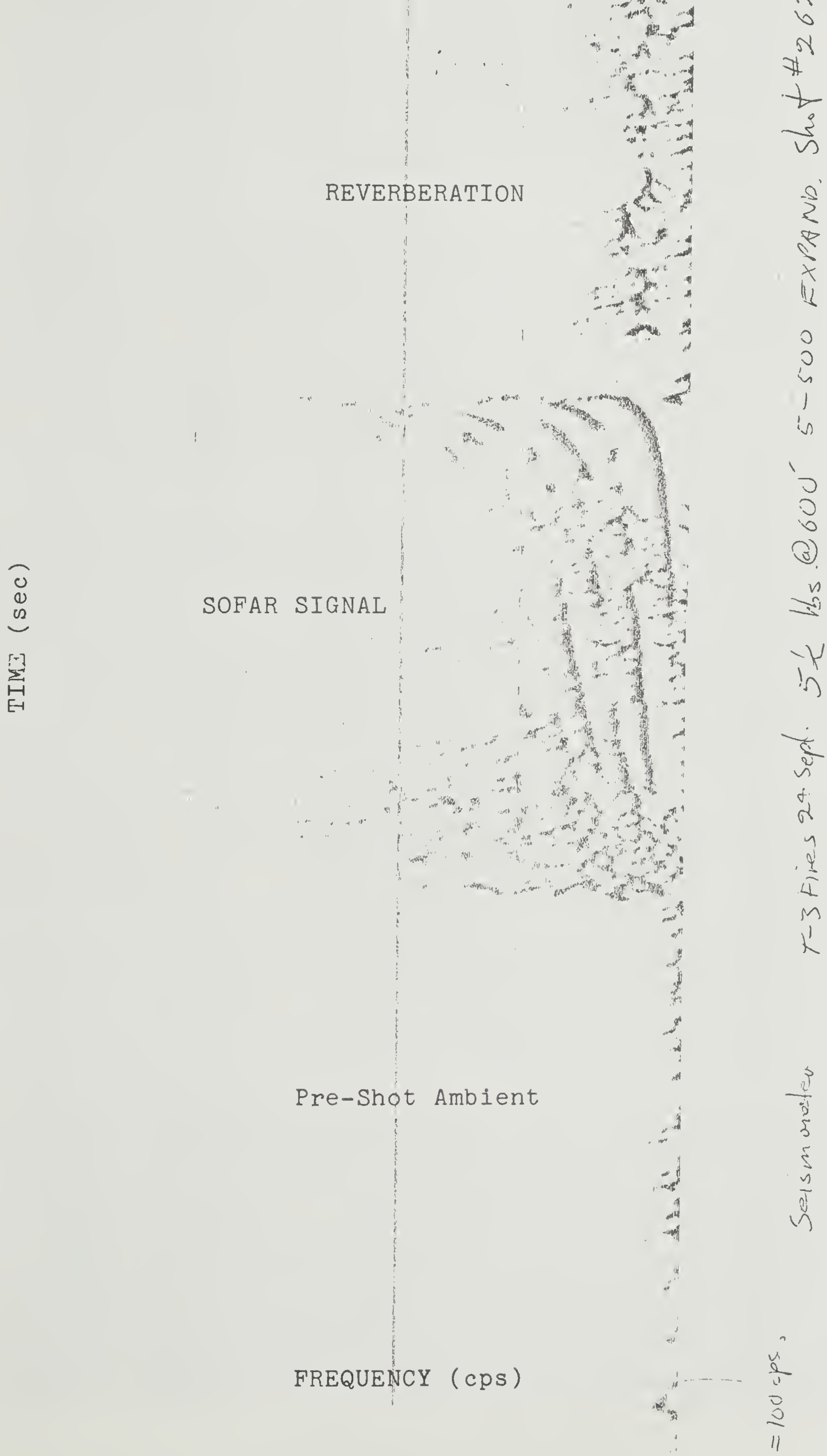


Figure 26. **ICE TREMORS** 26 April 62

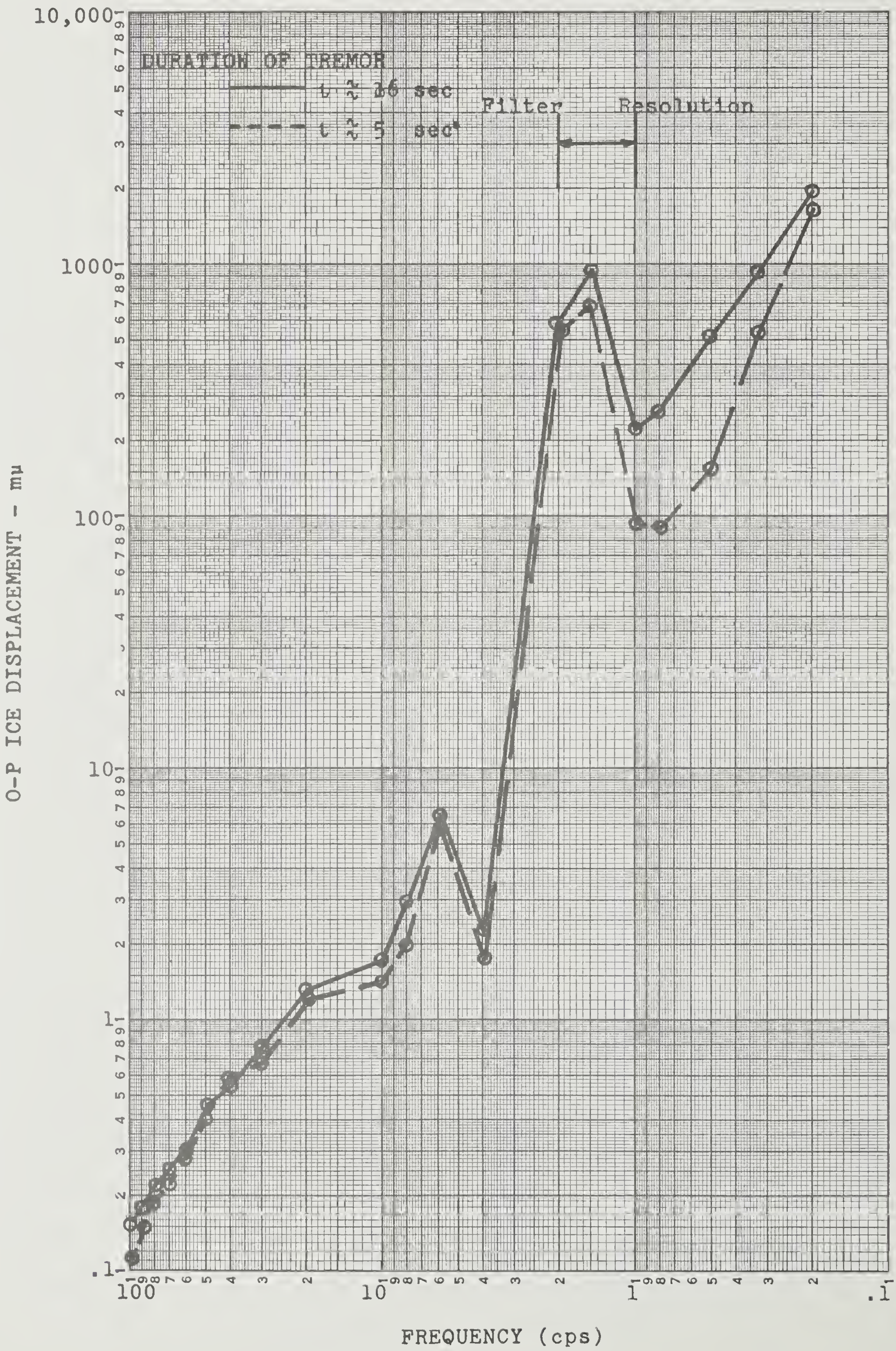
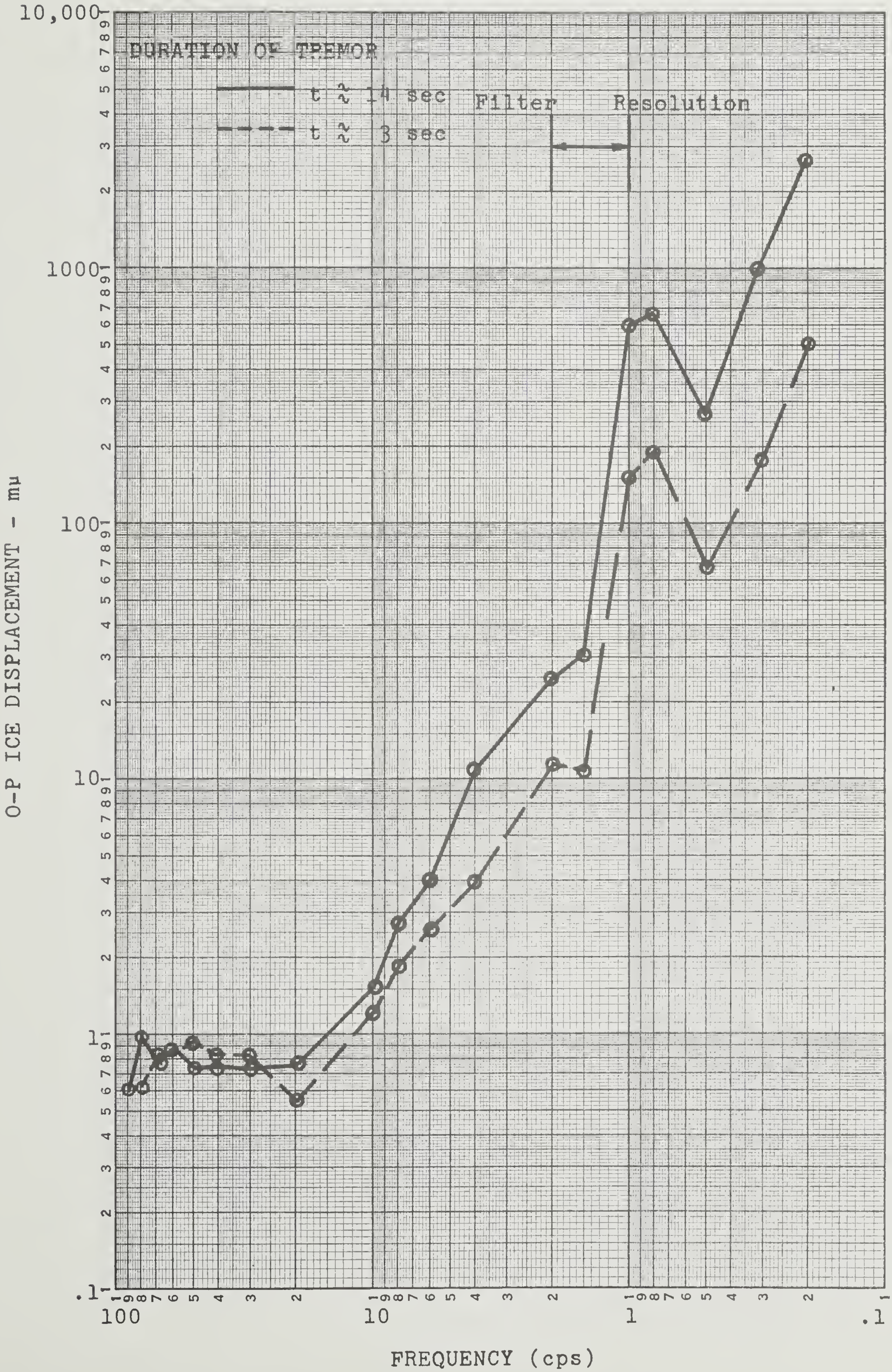


Figure 27. ICE TREMORS 27 April 62



SIMPLE FLEXURAL WAVE

RAGGED FLEXURAL WAVE

FIGURE 28

Figure 29.
SOFAR SHOT 26 APR 1962 - 17 pounds at 500 feet from POLAR PACK

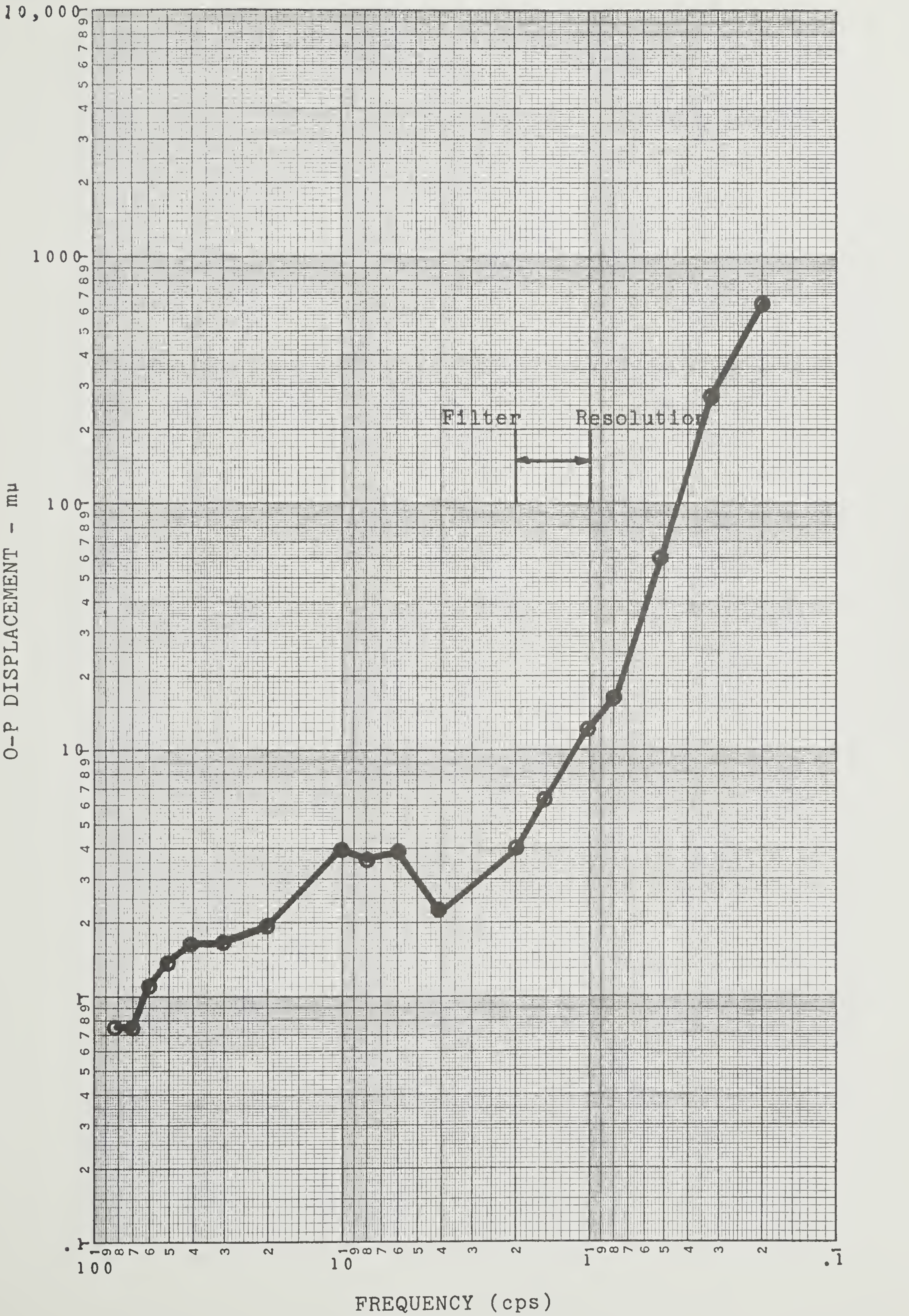


Figure 30
SOFAR SHOT 25 APR 1962 - 17 pounds at 500 feet from POLAR PACK

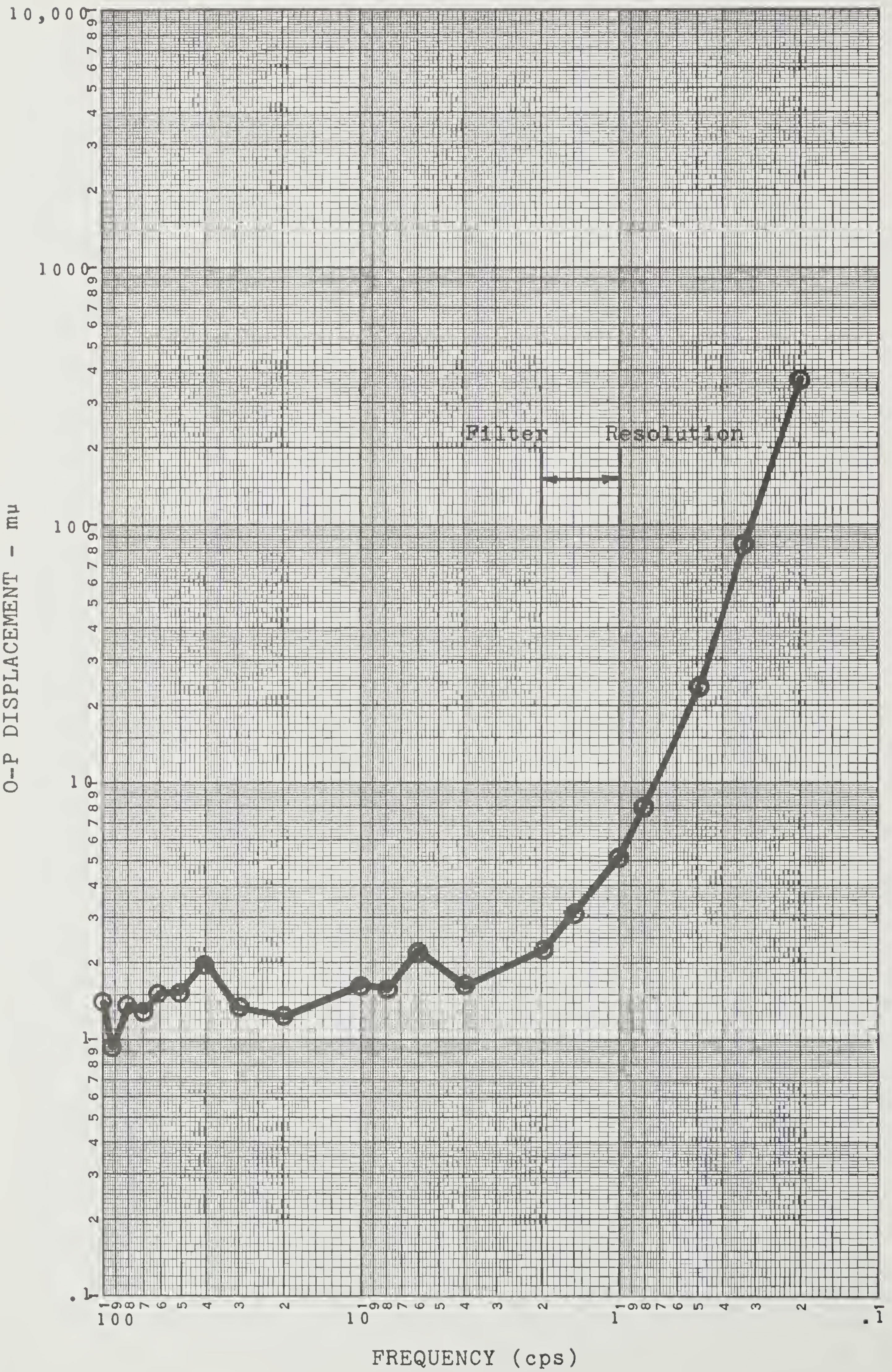


Figure 31.
SOFAR SHOT 25 APR 1962 - 17 pounds at 600 feet from Polar Pack

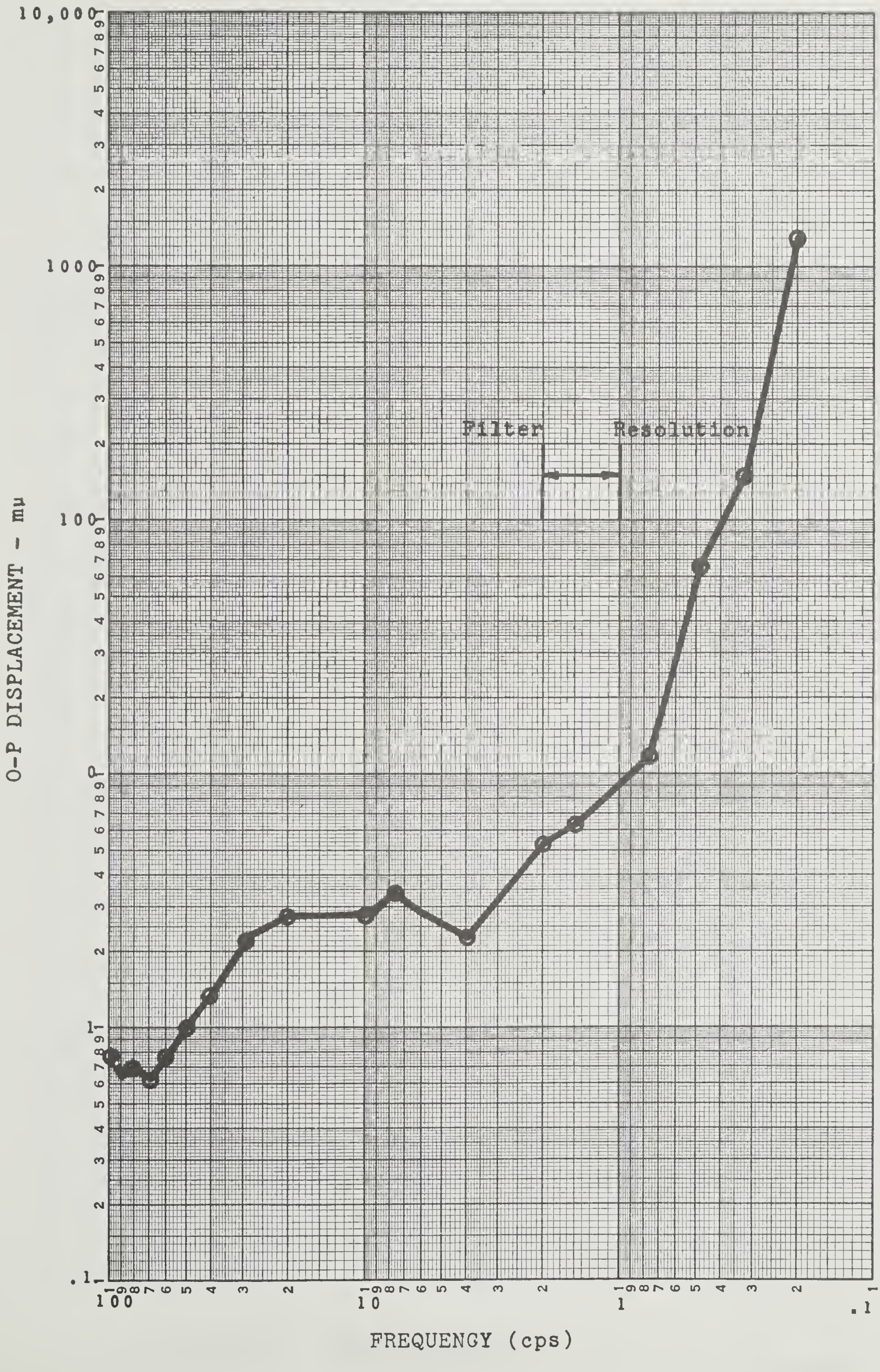


Figure 32.
SOFAR SHOT 25 APR 1962 - 50 pounds at 200 feet from T-3

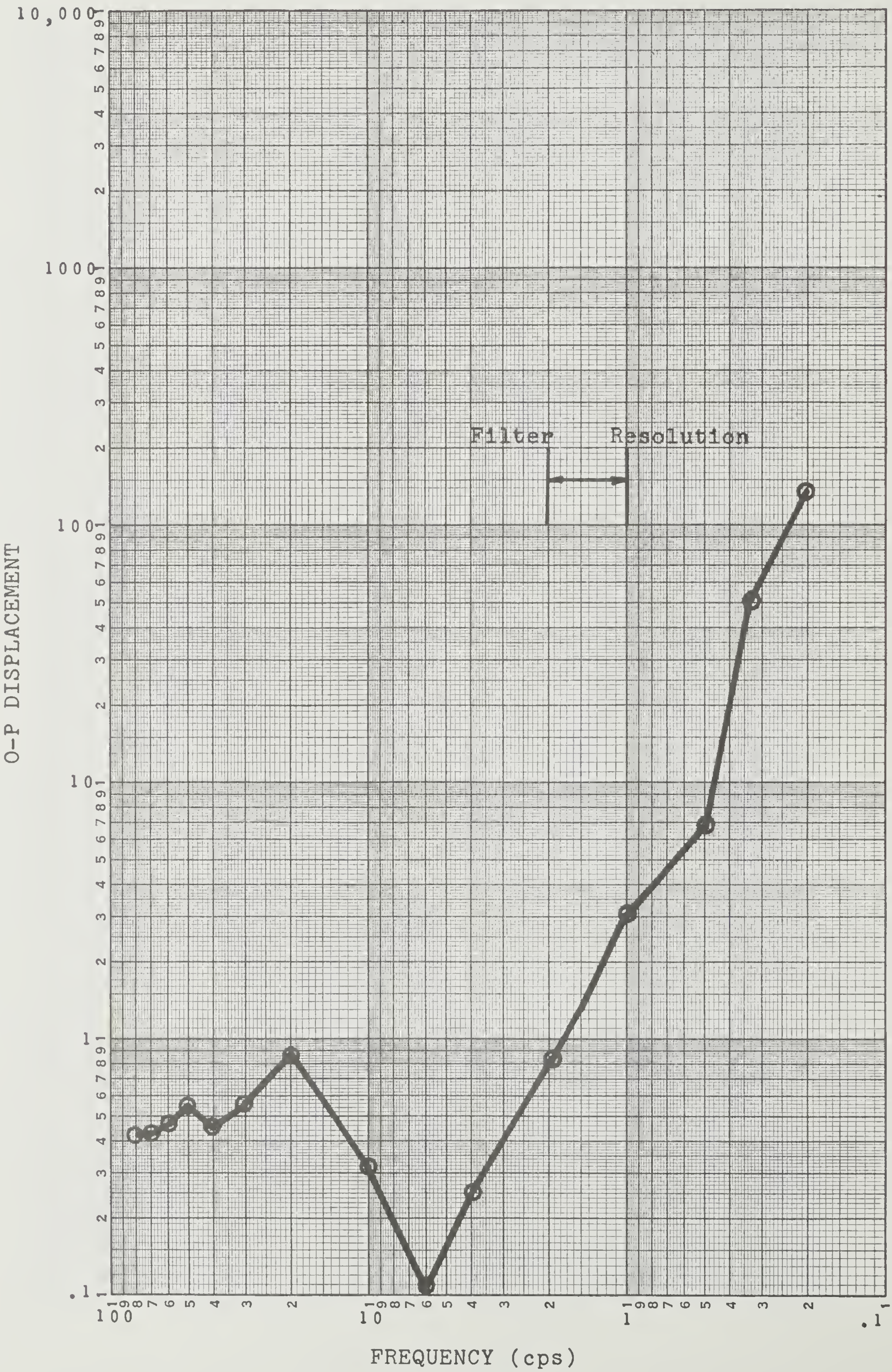


Figure 33.
SOFAR SHOT 25 APR 1962 - 50 pounds at 400 feet from T-3

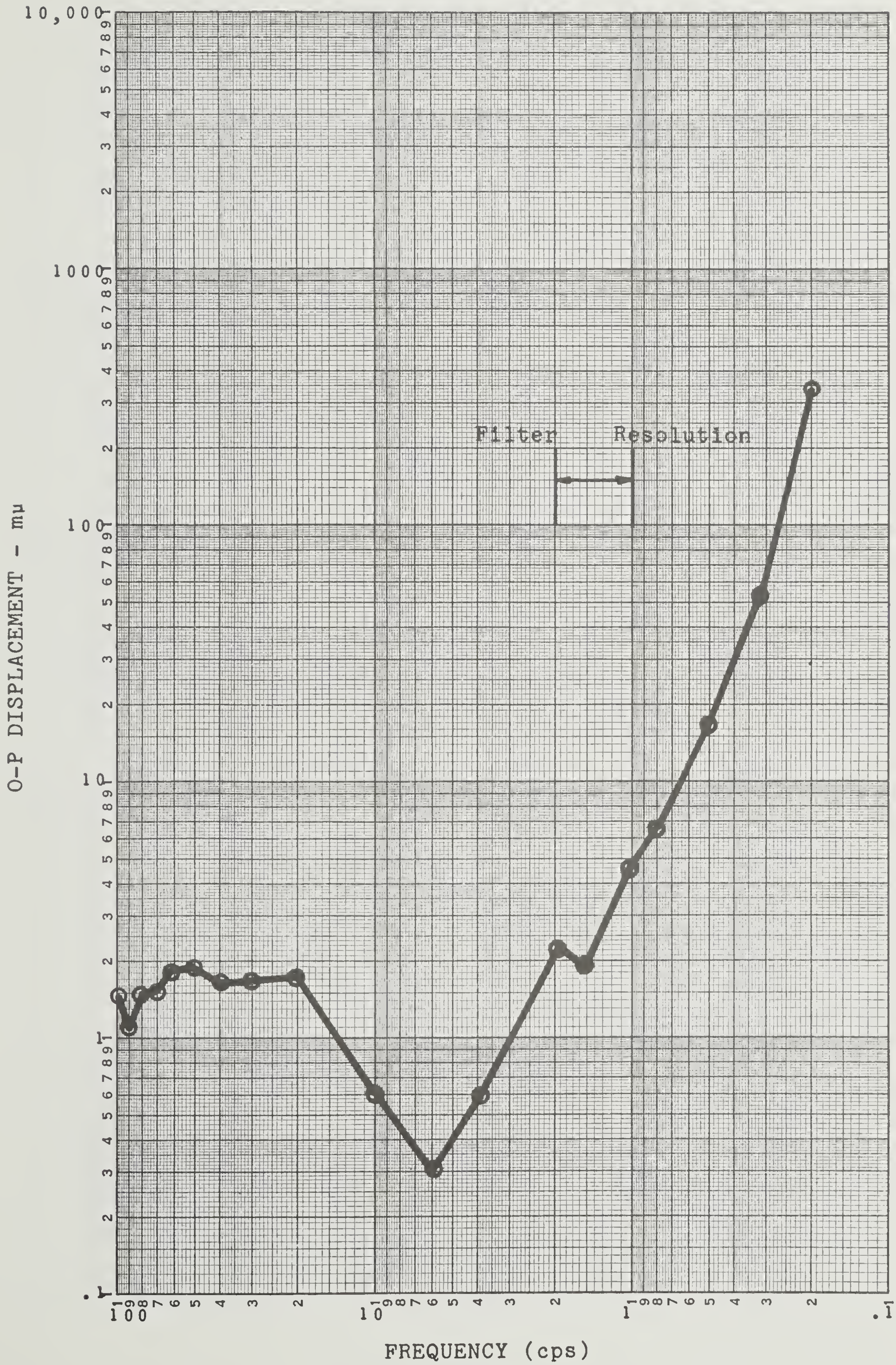


Figure 34.
SOFAR SHOT 25 APR 1962 - 50 pounds at 600 feet from T-3

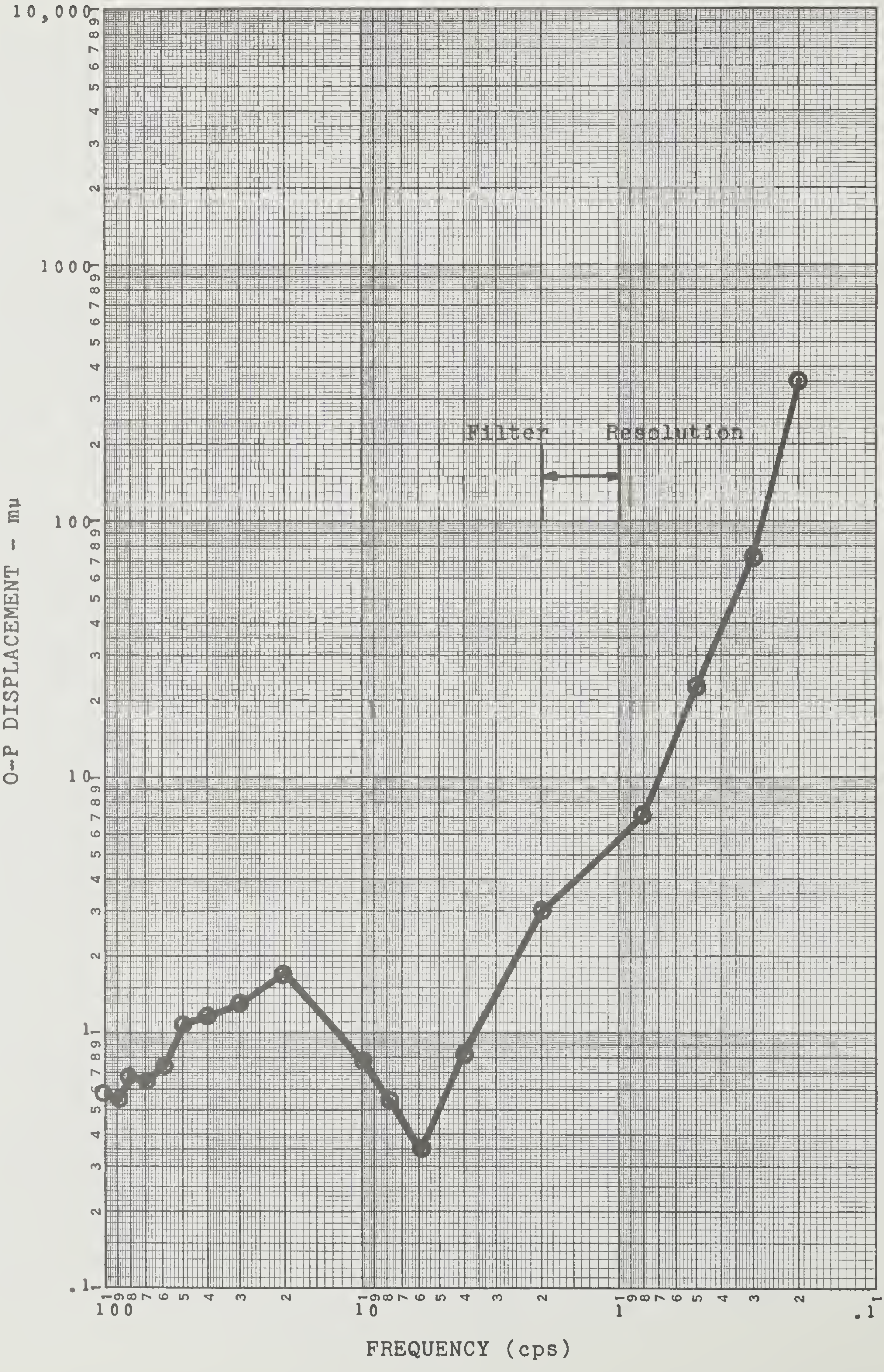


Figure 35.
SOFAR SHOT 25 APR 1962 - 50 pounds at 800 feet from T-3

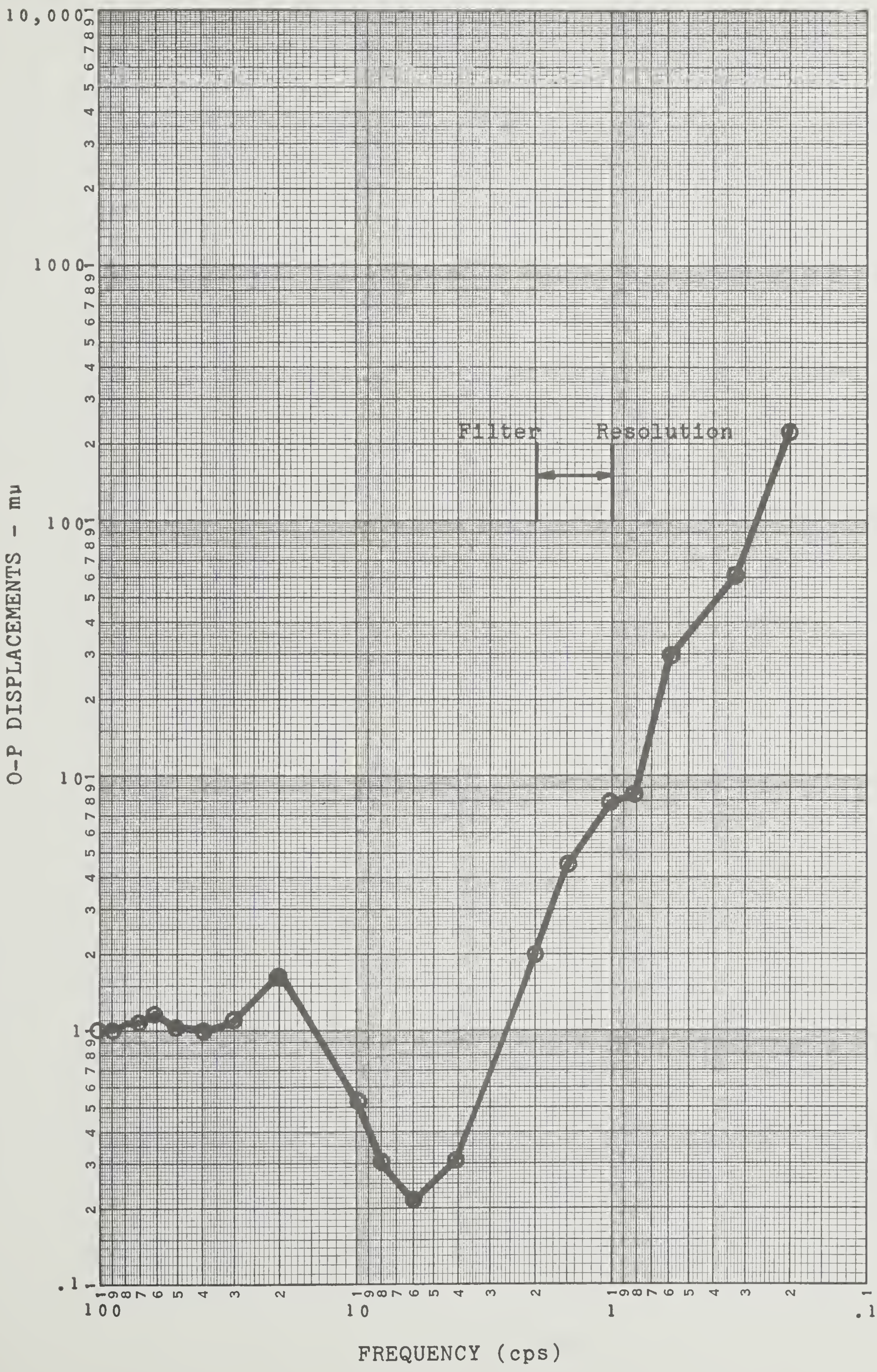


Figure 36.
SOFAR SHOT 27 APR 1962 - 10 pounds at 600 feet from POLAR PACK

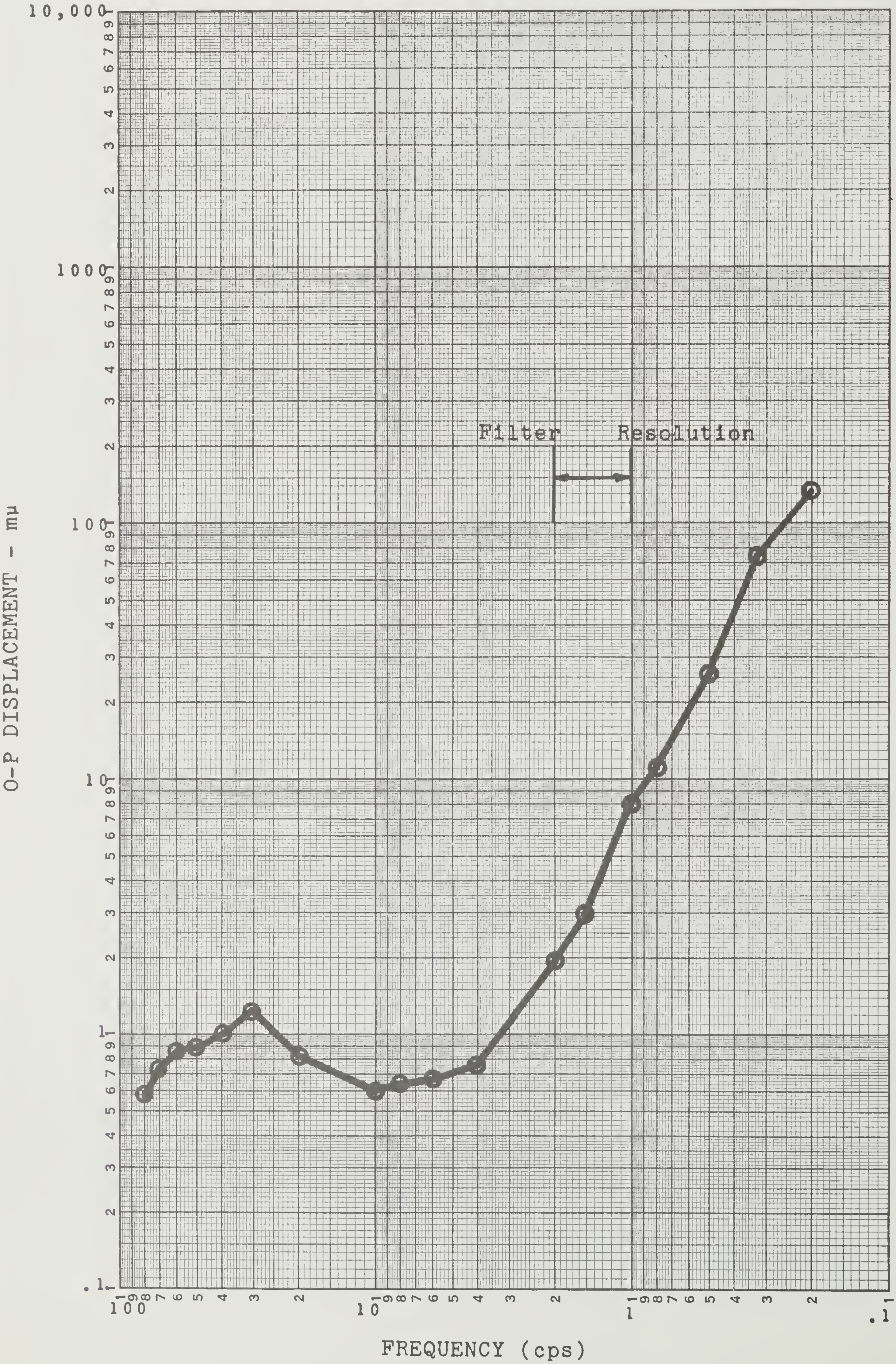


Figure 37.
SOFAR SHOT 27 APR 1962 - 10 pounds at 600 feet from POLAR PACK

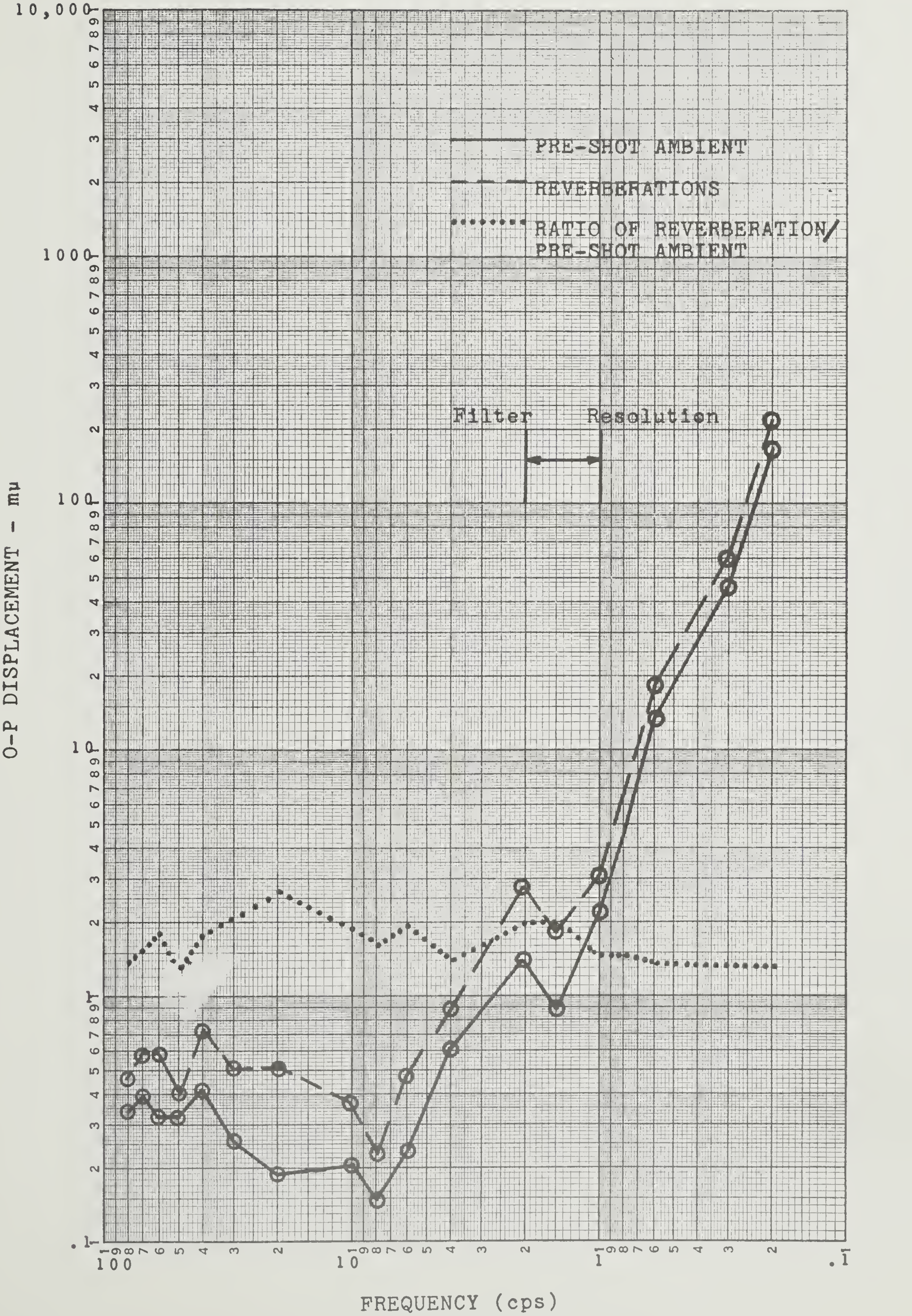


Figure 38.
SOFAR SHOT 25 APR 1962 - 17 pounds at 600 feet from POLAR PACK

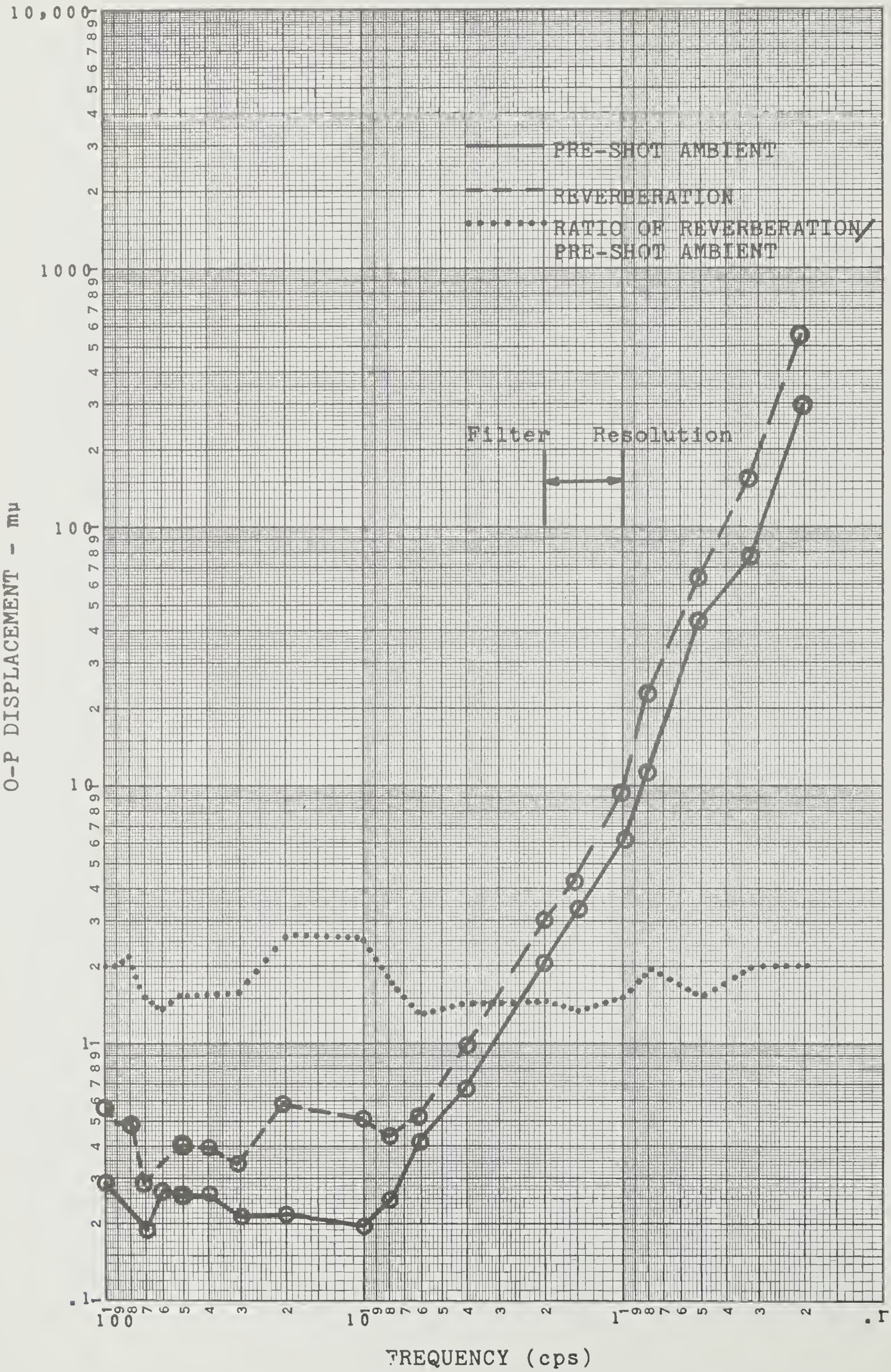


Figure 39.

SOFAR SHOT 25 APR 1962 - 50 pounds at 200 feet from T-3

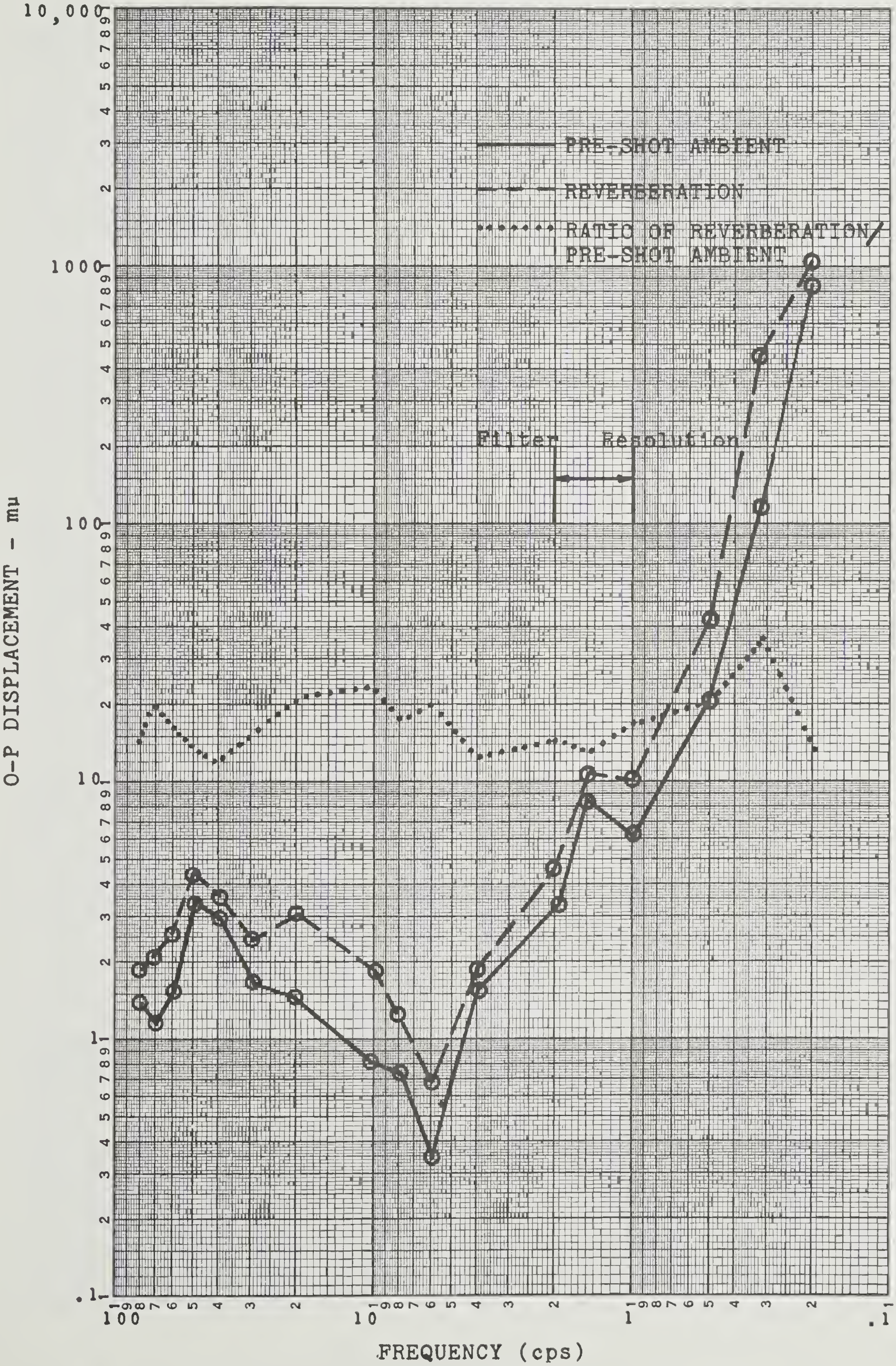


Figure 40.
SOFAR SHOT 25 APR 1962 - 50 pounds at 400 feet from T-3

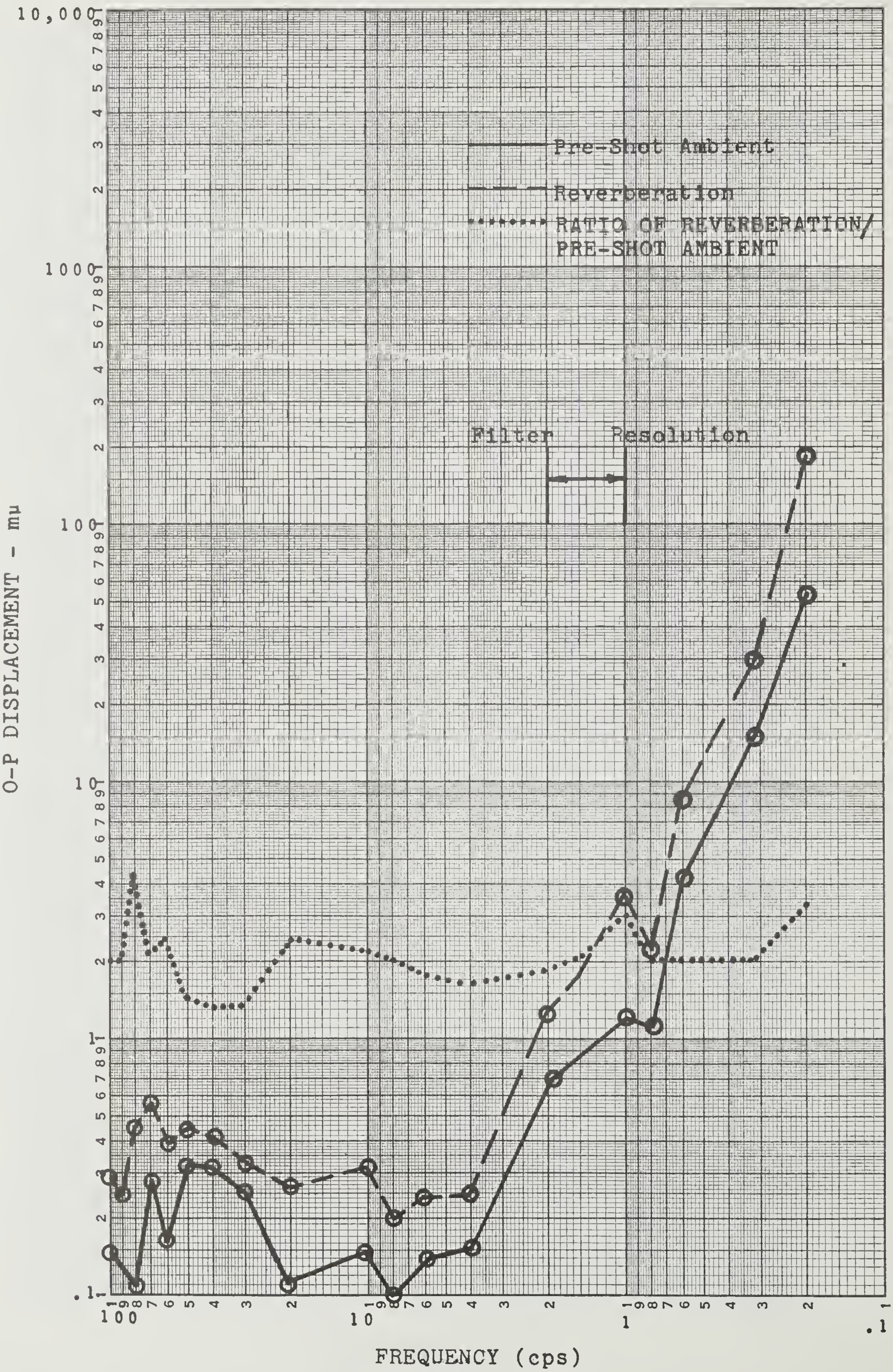


Figure 41.
SOFAR SHOT 26 APR 1962 - 10 pounds at 300 feet
D ≈ 3000 feet from GEOPHONE

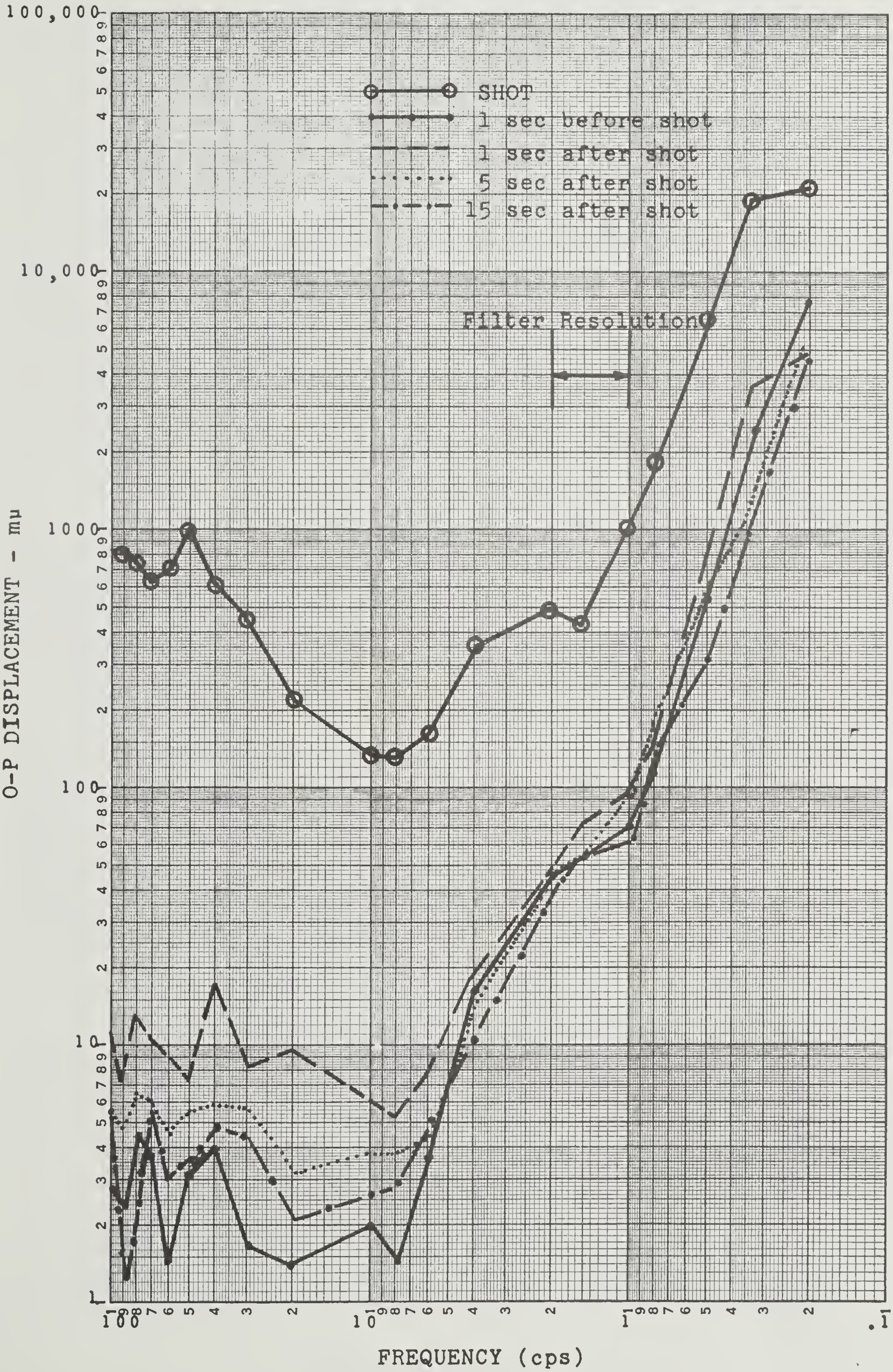
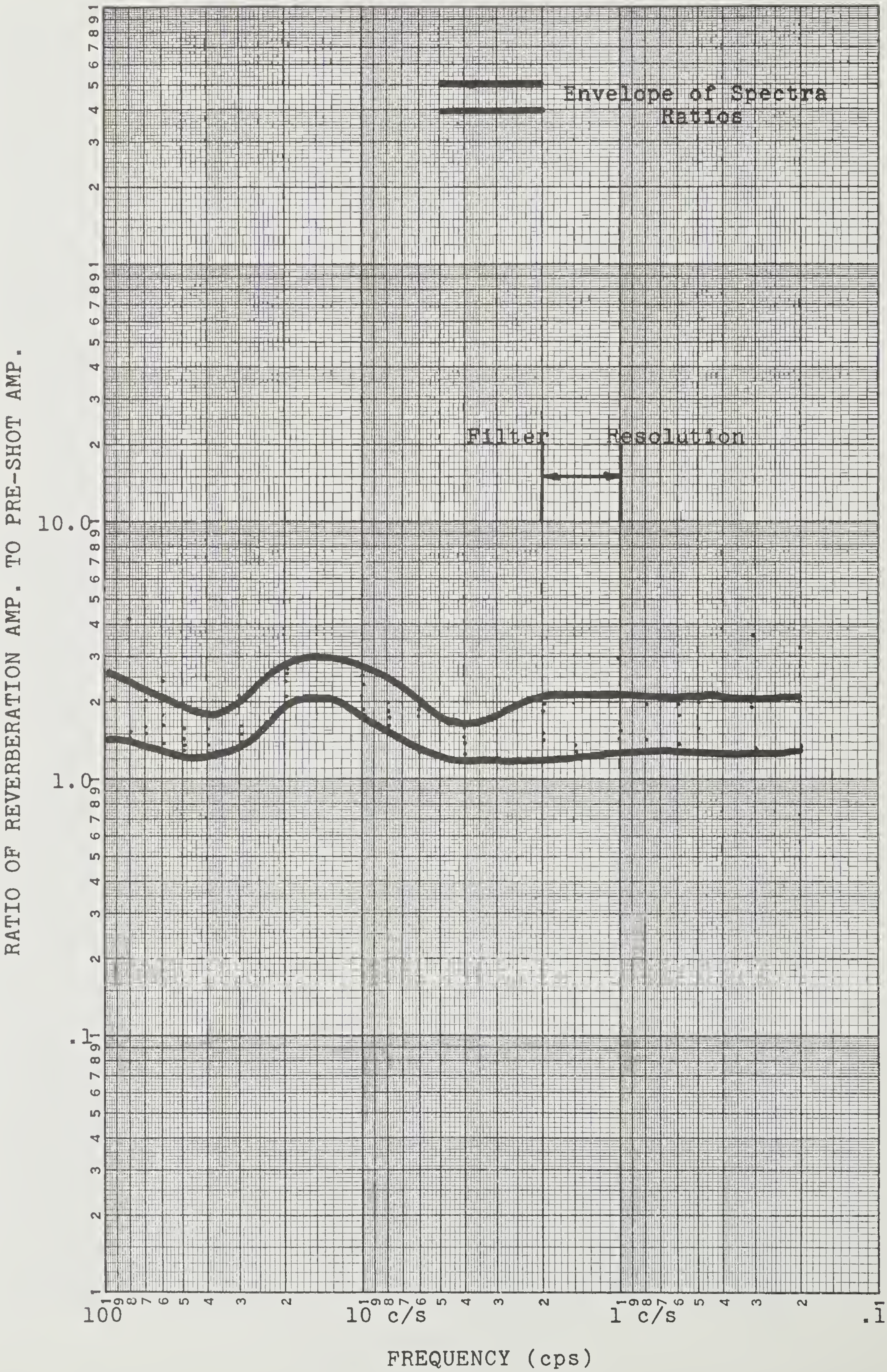


Figure 42. AMPLITUDE SPECTRA RATIO



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3 REPORT TITLE

Natural and Man-Made Ice Vibrations in the Central Arctic Ocean in the Frequency Range from 0.1 to 100 CPS

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5 AUTHOR(S) (Last name, first name, initial)

Prentiss, David; Davis, Edward; and Kutschale, Henry

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13 ABSTRACT

During April and May, 1962, ice vibrations in the frequency range from 0.1 to 100 cps were measured aboard drifting ice island ARLIS II in the central Arctic Ocean. A vertical-component seismometer, which was anchored to the surface of the island, was employed as a detector. Typical displacement spectra show the following characteristics:

(1) a nearly constant decrease in amplitude with increasing frequency from 2.4×10^4 mμ at 0.1 cps to 1.0 mμ at 6 cps
(2) an amplitude minimum of 0.1 mμ between 6 and 10 cps
(3) an amplitude peak of 2 mμ between 30 and 70 cps

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater Sound Ambient Noise Arctic Ocean Sea Ice						

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